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The fire of Hephaestus: The metaphysical and technological phenomenon of experimental physics

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THE FIRE OF HEPHAESTUS: THE METAPHYSICAL AND TECHNOLOGICAL PHENOMENON OF EXPERIMENTAL PHYSICS.

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ABSTRACT

Scientific realists have argued that a realist interpretation of physics is necessary if we are to make the results and successes of experimental physics intelligible. This thesis presents a phenomenological exploration of the operational metaphysics and technological structure of the phenomenon of experimental physics. The purpose of this thesis is twofold. It aims to address the transcendental question of how experimental physics is possible. It also aims to explore how experimental physicists have used technology to understand Nature. I shall present a critical, philosophical exploration of the work of experimentalists from the onset of experimental physics in the sixteenth century, the nineteenth century experiments on electromagnetism, to the contemporary experiments of Ultra-Low Temperature Physics and High Energy Physics. This exploration will be used to reveal experimental physics as an art, a teleological labour process, and as a mode of Heidegger's *Ge-stell* challenged to disclose its own possibilities by making them happen. It will critically examine the operational metaphysical precepts that are required for experimental physics to be presented as a mode of disclosure of "natural mechanisms" and "natural laws", situating them within "the grand experiment" that Jacque Ellul termed "the societal gamble".

CONTENTS

CHAPTER ONE

THE SPIRIT OF THE ENTERPRISE:

"Nothing requires greater nicety, in our inquirics concerning human affairs, than to distinguish what exactly is owning to *chance*, and what proceeds from *causes*; nor is there any subject, in which the author is more liable to deceive himself by false subtleties and refinements. To say, that any event is derived from chance, cuts short all further inquiry concerning it, and leaves the writer in the same state of ignorance as the rest of mankind. But when the event is supposed to proceed from certain and stable causes, he may then display his ingenuity, in assigning these causes; and as a man of any subtly can never be at a loss in this particular, he thereby has an opportunity of swelling his volumes, and discovering his profound knowledge, in observing what escapes the vulgar and ignorant."

David Hume (*Of the Rise and Progress of the Arts and Sciences*, 1965, pp. 421-422)

"Cause and effect: such a duality probably never exists; in truth we are confronted with a continuum out of which we isolate a couple of pieces, just as we perceive motion only as isolated points and then infer it without actually seeing it."

Friedrich Nietzsche (*The Gay Science,* aph. 112)

Entering the Cave of the Shadow-Puppeteers:

On the border between France and Switzerland, just a few kilometres north of Geneva, is the CERN site. At ground level there is nothing particularly remarkable about this place. It appears to be a sprawling industrial estate of prefabricated warehouses and squat office blocks. People move to and fro, carrying out a day's work in a way that seems as everyday and common as the working day of millions of people all over industrialised Europe. What is it that these people are doing? Why are they here? To answer these questions we must examine what is hidden from view. One hundred metres below the surface is a twenty-seven kilometres in circumference tunnel that has been carved out of the rock. It circumscribes the CERN site. Inside that tunnel is a machine called the LEP ring. It is a twenty-seven kilometres in circumference metal tube, closely surrounded by electromagnets and radio-frequency cavities. The LEP ring is broken at four equidistant points on its circumference by four artificial caves. In each chamber is a massive machine that is moved into its position by its own undercarriage caterpillar tracks. These machines are named the ALEPH, OPAL, L3, and DELPHI detectors. Each of these machines is a ten metre by ten metre barrel of electronics, wires, cells of noxious chemicals, and a huge solenoid, surrounded by a massive yoke of iron.

When the connected quintet of machines are operational no one is permitted underground. People monitor the performances of these machines remotely on computer screens and digital read-outs.

In the north west of England, just south of the city of Lancaster, is Lancaster University. In room "A522" of its School of Physics and Materials there is an Ultra-Low Temperature Physics laboratory. This room is quite large, slightly smells of grease and oil, and there is the constant low hum of pumps. The view is of pipes, barrels, gauges, dials, benches, tools, and four separate sealable rooms inside "A522", as well as two tiny offices tucked away at the far end. People move freely between the rooms inside "A522". They talk, joke, laugh, shout, and argue, as they move purposefully between the rooms. The atmosphere is one of constant and confident activity. The rooms are entirely screened in a cage of metal gauze; each can be sealed by a metal door upon which, on the outside, a sign reads: "If door closed ask permission before entry". [1] Inside each of the four sealable rooms are electronic devices, such as their amplifiers, frequency drivers, computers, junction boards, and meters, shelved around the room from the floor to the ceiling. There are also pipes, gauges, dials, and wires clustered around each other across one half of the ceiling. Wires and pipes radiate to and from a space enclosed by three ten feet walls of concrete blocks. This ensemble of fifty tons in weight can be raised on high-pressure jets of air to suspend it millimetres above the ground, by building it and turning a valve with one hand. Suspended in the partially enclosed space between these walls is a dilution refrigerator. This machine is an inverted, slightly conical, eight foot by three foot vertical skeleton of thin metal tubes, horizontal circular plates, electronics, screws, and bunches of wires, that hangs suspended over a pit in the floor by an ensemble attached to the top of the walls. The ceiling pipes and wires lead to and from the dilution refrigerator, via the overhead ensemble. At the very bottom of the machine is a small plastic container called "the experimental cell". The machine is made operational by building it, connecting it to the electricity mains, switching it on by pressing buttons, pumping cryogenic liquids into it, adjusting the settings on calibrated dials and digital displays by turning dials and pressing buttons, and waiting. When it is operational it is encased in a black metal container (holding cryogenic liquid nitrogen, which completely surrounds the dilution refrigerator) and is veiled by plumes of cold vapour. People monitor the output of these silent machines on computer screens and digital read-outs whilst they wait.

What are these machines for? What do they do? What do they produce? What is their function? What are these people doing with these machines? What are they waiting for? Why were these machines built? These people claim that they are physicists and that they use these machines, as well as other kinds of machine, for a very specific purpose. They claim that they are using these machines to find out how nature works. They claim that the purpose for building and using these machines is to satisfy their curiosity regarding the natural world and how it works. They claim to use these machines to make and refine pictures of how change in Nature works in terms of hidden "natural mechanisms". Furthermore, they claim to be able to use these refined pictures of "natural mechanisms" at work to innovate new machines and, by doing

[1] I would like to thank the members of the Lancaster Ultra-Low Physics Group for allowing me to enter their laboratory, see them at work, and ask them dumb questions.

so, increase their understanding of how invisible "natural laws" work. These machines are built and used by physicists to discover "the truth" about "the fundamental principles of the Universe" by working out how these machines work in terms of fundamental principles. It is this use of machines to discover "natural mechanisms" and "the truth" that is the subject of this thesis. As well as building and using these machines to acquire money, fame, glory, and for its own sake, as a pleasure, physicists also pursue their technical art to learn truths and satisfy their curiosity about change and permanence in the natural world. These machines are used to disclose the truth of how the natural world works. How is it possible that an artificial pursuit such as experimental physics could be taken to be a natural science? How is modern physics possible?

The Spirit of the Enterprise:

My purpose, in writing this thesis, is to elucidate the *operational* metaphysics that was used to make experimental physics *possible* as a means to obtain knowledge about the structures, mechanisms, laws, and content of Nature. This metaphysics is distinct from *induced* or *speculative* metaphysics, such as Gassendi's seventeenth century atomic theory of matter, or Newtonian absolute space and time, or Everett's many-world interpretation of quantum mechanics, for example. These were proposed in order to make the results of experimentation intelligible in terms of particular conceptions of Nature. Both kinds of metaphysics are necessary for experimental physics to progress but, whereas particular metaphysical conceptions of particular experiments are replaceable and contingent, the operational metaphysics is universally presupposed by every particular experimental apparatus; it is a requirement for experimentation using machines to be a means of ontological access and epistemological warrant. I have termed this operational metaphysics as *mechanical realism*. This metaphysics is a condition for experimental physics to be a natural science and has been implicitly presupposed by subsequent induced metaphysics since experimental physics began. It has endured through the subsequent paradigm shifts from mechanical physics to quantum mechanical physics, and from the indubitability of Euclidean geometry to the indubitability of non-Euclidean geometry. The physicists' interpretations of the shadows on the cave wall may well have changed, from time to time, but the project of using shadow-puppetry to make those shadows has persisted throughout. It is my view that, if we wish to understand the phenomena of experimentation, we should try to understand it from within as broad as perspective as possible. This involves studying the ways that physics is connected within the wider world of human affairs. It also involves studying it within the confines of the laboratory. If we are to understand its external and internal trajectories, and how they inter-relate, then we need to study how physics works on both macroscopic and microscopic levels. We would also need to understand its histories.

I have assumed, from the onset, that any understanding of the experimental sciences should be based upon an understanding of technology, when those sciences use technologies as the means to explore the natural world and our understanding of our place in it. The argument of this thesis is not premised upon the assumption that technology is a neutral means. The directions, performance, and results of experimental research are shaped by the available technologies required to perform particular research projects. Anything that can not be disclosed via publicly accepted techniques of disclosure is excluded from being included as an object for research by sciences that are premised upon the legitimisation and justification of techniques. These techniques, if they are to be candidates for acceptance, must be either comprehensible or repeatable, and ideally both. The "objects" of theoretical physics must be both graphically visualisable and technologically manipulable in order to be intelligible and available objects for experimentation and mathematical modelling. Theoretical and experimental practices are linked by making visual representations of "invisible entities" (such as "subatomic particles", "space-time curvatures", "superstrings", and "electromagnetic fields") that can be related to practices through the mediation of calibrated instruments and communication. How are theories and experiments linked this way? I shall argue that theoretical objects are discursively linked to technological objects by using a conception of mechanism as the link between natural causes and effects.[2] The internal relationship between theoretical and technological practice is a series of implementations of mechanisms to the progressive development of the content of both theory and technology. The character of the knowledge that experimental physics is directed to achieve is that a complete account of the unchanging first principles of causal change which govern the performances of the experimental apparatus. Such performances are the responses of the apparatus as a result of human interventions and are taken by experimental physicists to disclose natural mechanisms at work. Knowledge of such principles of change have the characteristic form of a theoretical knowledge of how change happens due to the actualisation and exercise of natural causes, mechanisms, powers, and structures in accordance with natural law. In this thesis this kind of scientific knowledge will be analysed in terms of ancient Greek *episteme* and *techne* to reveal the implicit metaphysical precepts that allow knowledge of "natural laws" to be possible on the basis of technological practices and interventions using machines.

Techne (plural: *technai*) had a loose meaning of art, craft, or science in pre-socratic Greek.[3] It had the connotation of "device" in the straightforward sense of "ploy" rather than "something devised". It had similar meaning to "crafty" and "artful". In ordinary usage *techne* was used to refer to cleverness and cunning in getting, making, or doing, as well as to trades, crafts, and skills of every kind. It involved a collection of tactics, stratagems, and tacit "know-how" as kinds of activity to achieve specific ends. It was in the philosophical writings of Plato and Aristotle that *techne* was treated as a formal kind of knowledge

[2] This is also apparent in the historical development of the sciences of psychology and artificial intelligence. See *The Mechanization of the Mind: On the Origins of Cognitive Science* by Jean-Pierre Dupuy (trans. DeBevoise, Princeton University Press, 2000) for an excellent discussion of this.

[3] Τεχνη is commonly translated (see OED or the Liddle and Scott Greek-English Lexicon for example) from the Indo-European stem *tekhn-* ("woodwork" or "carpentry") as "art", "craft", "know-how", or "skill". The Greek *tekton* and Sanskrit *taksan* are translated as "carpenter" or "builder". Sanskrit *taksati* is translated as "forms", "constructs", or "builds". The Hittite *takkss-* is translated as "to join" or "to build". The Latin *texere* is translated as "to weave".

which, as a theoretical kind of knowledge, could be used to guide or govern making. For both Plato and Aristotle *techne* referred to the general, abstract, and communicable first principles of making and inscription in the activities of craftsmanship and art. It is how *techne* was related to *episteme* (commonly translated as "science" or "knowledge of eternal and necessary principles") that revealed the difference between Plato and Aristotle.

In Plato's works, *techne* and *episteme* were closely related when discussing art and knowledge in general and were used interchangeably to characterise geometrical reasoning in particular. In *Philebus* (55c-56d), *Statesman* (258e), *Gorgias* (450b-c), and *Ion* (532), for example, Plato used *episteme* to describe mathematical truth as eternal and necessary knowledge whilst using the word *techne* to describe mathematics (including logic, arithmetic, and geometry) as the highest form of art. Socrates often argued that all *technai* are involved with *logoi* (words, speech, reason, principles) bearing upon some specific subject matter of the art in question, even though some require a great deal of physical exertion and very little reason (i.e. horse riding, painting, or sculpture) and others require a great deal of reason and very little exertion (i.e. arithmetic, logic, or astronomy). Only routine activities (i.e. cooking or persuading), unreflectively based upon experience and habit, devoid of *logoi* were considered to be *atechnos* (devoid of art). Of course such activities, such as cooking or persuading, can be (and are) developed into arts, but for everyday purposes the usually are not. According to Socrates, what such activities lacked, in order to qualify as *techne*, was knowledge of the *aitai* (intelligible causes) involved in what was made or done. Such everyday habitual and unreflective practices were *alogos* (without words, reason, or principles). A *poiesis* (productive activity) needed to be teachable through *logos* in order to qualify as *techne* and henceforth *techne* was the knowledge of all productive activities that could be reasoned about and taught. It was the logical and communicable knowledge regarding the causal principles involved in making or doing something. It could either proceed by conjecture and intuition based on practice, training, and instruction (i.e. music, medicine, or agriculture), or it proceeded through the use of numbering, measuring, or weighing. The later was taken to be the higher form of *techne* because it involves the greater exactness or precision. The mathematical activities of numbering, measuring, or weighing were taken to be the most truly *technai* because they were taken to involve the greatest precision and were more closely associated with the activities of making that operate upon the material world. These reasoned activities operated by guiding acts of making through the use of mathematics, and the *techne* of such activities, provided a formal knowledge and rules by which material practices were performed, governed, and understood. However, in *Philebus* (56d) *epistemoi* such as arithmetic were distinguished from *technai* such as carpentry because the former deals with abstract numbers whereas the latter uses numbers to deal with materials. In *The Statesman* (258e) *episteme* was used to denote pure theory or any knowledge that did not relate to the material world in a practical manner. *Episteme* was reserved for knowledge learnt for its own sake.

Aristotle, following Plato, also defined *techne* as a kind of knowledge of making or production that informed material practices. He used the word *techne* (NE 6.4; Meta. 1.1; Rhet. 1.2) to refer to any theoretical knowledge concerned with making that was explanatory, generalised, abstract, formal, and communicable. *Techne* was induced from unarticulated particular experiences and practices into communicable, formal, and general knowledge of the first principles (or intelligible causes) involved in making or producing something. It was to be used to reason about how to make particular things in a specific manner. It was the general knowledge of the principles and causes, the know-how and the know-why, of any specific art or craft. It was inextricably bound up with an intellectual grasp (consciousness or cognition) of first causes that provided the kind of knowledge possessed by a *technite* (an expert) in any one of the specialised crafts. *Techne* provided "a true course of reasoning" that guided stable dispositions to make particular things or bring about a state of affairs in a specific manner (NE 6.4.1140a11). It was distinct from experience because the latter could only be related to the particular, whereas the former was concerned with the general and was to be used to explain the particular. Someone may have the experience that outcome B will sequentially follow action A but, without a complete account of why B follows A, that person would not possess *techne*. *Praxis* (habitual practices) could be learnt from experience and mimicry, and be used to develop tacit, non-verbalised skills and beliefs regarding "the best way to proceed". However, it was only when this acquisition of experiences and instruction had been completed (inductively abstracted in a general true course of reasoning) that *techne* could be acquired. The craftsman needed to give a "rational account" of *praxis* before s/he could be said to be a *technite*. This "rational account" was to facilitate the tracing back of a product to its causes.

Aristotle argued that the materials used in production were distinct from the *technite* and *techne* was not contained in the produced thing or state of affairs. Aristotle made a distinction between *poieta* (things that find their origin in the maker) and *phusika* (things that find their origin in themselves). The activities of *poiesis* (bringing-forth, production) were taken to bring about and terminate in a product, outcome, or *telos* (end) that was separate from them. A pot is brought-forth through the actions of the potter, whereas a tree is brought-forth in accordance with an internal principle of change. Aristotle considered *poiesis* guided by *techne* to be distinct from *phusis*, yet he used his conception of *techne* as his primary analogy in his elucidation of his conception of *phusis* (whilst maintaining the autonomy of the latter).[4] He used *techne* to elucidate his conception of *phusis* as teleological (frequently requiring *tuche*, meaning luck or chance, as a tripartite division). When *telos* was introduced through the activity of a *technite* the source of change was separate from the thing in which the change happens, something could be considered to be *phusika* when the source of change was immanent within the thing itself. *Techne* was the possession of the most helpless, unshod, unarmed, unclad, but highest animal who could, through *techne*, turn this weakness around, take advantage of *phusis*, and even complete that which *phusis* left incomplete (De Part. Anim. 4.10.687a24; Phys. 2.8; Pol. 1337a1-2.) For Aristotle, *techne* was rooted in and a completion of *phusis* (Phys. 193b10 and 2.1.193a12-17) to the extent that even human nature was completed by *techne* through medicine, crafts, and politics (Pol. 1.2.1253a2). Art imitates and completes Nature. It does this by attempting a union of form and matter that achieves a deep union in which the *telos* (the end) comes from within. Thus, for Aristotle, *techne* was directed towards perfection and the *technite*

[4] See *Physics* Bk.2, especially 2.2.194a22ff and 2.8.199a15ff.

must attend to the materials s/he works with. Within Aristotle's four-fold causality of formal, material, final, and efficient causes, it was the *technite* who took on the role of efficient cause. As "a true course of reasoning" *techne* was taken to be contained within "the soul of the craftsman" as "a reasoned state or capacity to make" and was consequently taken to be bound up with the maker. It guided the hands to perform definite motions that moved the tools and shape the materials into the product. This motion embodied *morphe* (shape) and *eidos* (form) into *hyle* (matter) and produced substance (informed matter). *Hyle* should not be confused with the post-sixteenth century conception of matter as inanimate and structured material.[5] *Hyle* referred to an unknowable and incognate formlessness, the formless potential to receive form that is active in the reception of it (Meta. 7.9.1034a10-11; Gen. An. 1.22.730b10-20). For Aristotle, no two lumps of clay were alike. *Hyle* was the particularity of any particular lump of clay and did not refer to the clay-like properties of the substance called "clay". It referred to the particularity of the particular. It referred to the way that a potter was unable to make the same pot twice and the way that each and every pot, as well as the experience of making them, were all different even though they were all made out of the same substance. It was this active and emergent particularity to which *hyle* referred (Meta. 7.8.1033b20-1034a7). Form could not be forced upon (or into) *hyle* because of this active character in the reception of form. The *technite* had to be responsive to the way that *hyle* received form and, although the form was in the soul of the craftsman, its union with *hyle* was directed by both *techne* and *hyle*. The extent to which the *technite* could impose form upon *hyle* was not entirely within the control of the *technite* and there was a definite limitation to the extent that *techne* could guide this union. It was only to the extent that *hyle* could be grasped by "the rational part of the soul", during the reception of form, that it could be known and be part of *techne*. It was for this reason that Aristotle argued that both *techne* and perception (especially touch) were required to guide the activities of making (NE 2.9.1109b23). The *technite* had to be responsive to the receptivity, capacities, tendencies of *hyle* emergent as the particularities of the materials during attempts to impose form upon them, just as much as s/he needed to know the appropriate forms, tools, materials, and how to combine them. The receptivity, capacities, and tendencies of *hyle* emergent during *poiesis* would hot have occurred without the intervention of the *technite*, but *hyle*, as the particularity of the particular, resists the imposition of the generality of form from having complete sway. Due to *hyle*, individual experiences of making could not be known in their particularity through the general *logos* of *techne*. Due to the generality of *techne*, the particularity of individual experiences could be emergent *qua* particularities. For Aristotle, general principles could not apply to all particulars and it was impossible to find universal statements that were always correct (NE 5.10.1137b13-15). It was *hyle* that resisted the characterisation of any *praxis* or *poiesis* under a single set of rules (or instructions) that could be communicated from *technite* to apprentice. Although *techne* was comprised of formal, communicable, general, and abstract principles of making, it was primarily learnt through imitation and attending to the particularity of the appropriate materials. Theory is an incomplete guide to action and human beings

[5] It is for this reason that, as Heidegger, Kuhn, and Feyerabend pointed out, Aristotle and Galileo's physics were incommensurable. They are describing two different things differently.

become builders by building (NE 2.1.1103a35). Aristotle defined *techne* in terms of a knowledge of the changeable and temporal, whereas *episteme* was reserved for knowledge of the eternal and unchanging. The subject matters of these two forms of knowledge were distinguished into two distinct realms: the temporal realm of Becoming and the atemporal realm of Being (Post. Ana. 2.19.100a6-9).[6] *Techne* was directed towards *episteme* due to its theoretical character as a general knowledge of the unchanging first principles of change, but it was distinct because its was directed towards temporal activity. *Techne* was a general knowledge of the Being of Becoming, whereas the particularity of activities evaded complete capture by generalities. Thus, for Aristotle, *poiesis* guided by *techne* was straddled on a continuum between particularity of practice and the generality of theory (Meta. 1.1.980b25ff).

A central problem for any analysis of experimental physics is the relation between theory and practice. Neither an uncritical acceptance of the "internal" discourse of working physicists nor a total rejection of it is helpful for the project of developing an understanding of experimental physics. Realists, such as Bhaskar and Hacking, despite their careful attention to the motivations of physicists, are too uncritical of scientific discourse in their analyses of the relations between theory and practice. Sociologists of science, such as Latour, Knorr-Cetina, Bloor, and Collins, have not sufficiently attended to the realist motivations that are central to the scientific enterprise of experimental physics. I agree with these analysts that the relations between theory and practice are those of legitimisation, and, in their terms, physicists are working in the context of the justification of their expertise and authority. It is also evidently the case that the motivations at play in any social activity are complex and many of the motivations for pursuing experimental physics are transcientific. Career, aesthetics, practicality, prestige, economics, pleasure, and authority, are all motivations for pursuing experimental physics. It may well also be the case that someone is a physicist just because they so happened to be good at it. However, curiosity and the desire for knowledge about natural processes are also motivations for pursuing the art of experimental physics. Working experimental physicists are also practitioners within the context of discovery. If we aim to understand physics then we need to address it from within both the contexts of justification and the contexts of discovery. As well as addressing the justificatory role of experimentation, an intelligible and satisfactory account should explain the possibility of scientific realist motivations and their satisfaction. The challenge for a non-realist interpretation of physics is to analyse the art of experimentation as a process of discovery without conceding scientific realism. It is a central aim of this thesis to rise to this challenge. I shall argue that the labour processes of experimental physics, like all labour processes, have a teleological character.[7] They aim to satisfy the purposes and challenges, which are central to the setting-up of any experiment. The practices and choices adopted in the execution of any experiment are made with the explicit aim of

[6] This distinction was central to the analyses of *techne* presented by Heidegger (1977), Dunne (1993), and Steigler (1998).

[7] Lukacs (1967) and (1978) argued for the teleological character of labour. He argued that labour processes are social processes in which they are organised upon the positing of ends. He termed this positing as "teleological positing". I shall discuss this in chapter four.

satisfying those purposes and challenges. I shall argue that genuine novelty in experimental physics is the product of a technical complex of heterogeneous component inventions combined into an ensemble, which is integrated with other ensembles in order to reproduce functionality. It is this integrated ensemble that I term as a machine. As Latour has persistently argued, all technological objects are complex and can not be understood without addressing their connections and interactions with other technological objects and the purposes that they were constructed to satisfy. Converging and integrating their components into a stable and unitary centre of transformative power produces all novel technological objects. The labour processes of experimentation are the refining processes of stabilisation directed towards producing transformative powers. When labour is performed for its own sake then the labour process is an art directed towards its own self-perfection. All arts are self-directed labour processes that produce themselves for their own sake. Experimental physics is an art aiming to achieve its own *techne* as well as a manifestation of the technological imperative of Hedegger's *Ge-stell*.[8] Heidegger was sensitive to the influence of technology upon human freedom and destiny. He recognised historical and life-world distinctions between pre-modern and modern technology. Heidegger (1977a) defined "pre-modern technology" as handicrafts (*techne*) and "modern technology" as an enframent (*Ge-stell*). For Heidegger, modern technology is a mode (attitude) of *revealing* that *sets-up* and *challenges* (*Ge-stell*) Nature to yield energy that can be independently stored and transmitted. A coal-fired electric power plant unlocks basic physical energies and then stores them up in abstract, non-sensuous thermodynamic forms. Modern technology generates a world of *Bestand* (resources, standing-reserve, stock, or capital) that are available for use. *Bestand* consists of objects that only have instrumental value. *Ge-stell*, enframing, is the transcendental precondition of modern technology as it gathers together human beings, challenges us (or sets us up), to reveal reality as *Bestand* (resources) through a mode (attitude) of Being termed as ordering. *Ge-stell* is not itself part of technology but is rather the attitude (or imperative) that is at the heart of, and wholly present within, modern technology. It is a technological attitude towards the world. It sets upon human beings and challenges us to set upon and challenge the world. Technology cannot be understood in terms of technology because, as *Ge-stell*, it conceals Being and, as a mode of Being, it thereby conceals itself. Modern technology, as a concealed mode of Being, enframes and directs the trajectory of human existence. It is a *destining*. I shall discuss this further throughout this thesis. It is through the deepening of this destining in the science of cybernetics, in terms of its transparency through embodiment and the illusion of the "steersman" metaphor, which brings with it an increasingly unquestioning relationship with modern technology. This brings with destining a danger to our chances of developing a free relation with technology. Heidegger (1962) addressed the question of technology *existentially* and emphasised the primacy of practical over theoretical concerns. In the 1949 version of his *Letter on "Humanism"*, Heidegger (1999, p. 259 fn.) noted that modern science had become the new metaphysics into which philosophy was becoming dissolved. The unity of this

[8] Ge-stell can also be translated from common German to mean "skeleton", "stand", "frame", or "rack". Lovitt (Heidegger, 1977a) translated *Ge-stell* as "enframing" and emphasises the connotations of *gathering* and *ordering* in its meaning.

metaphysics was unfolding, in a new way, in the science of cybernetics. The power of modern science, as a consequence of this metaphysics, belonged to *Ge-stell*, and could not be stopped because *Ge-stell* obscured the place of "the event of appropriation" (the origin of modern science). How does the power of modern science belong to *Ge-stell*? How are modern science and modern technology *metaphysically* connected? These questions are central to my analysis of the metaphysical foundations of modern experimental physics as a "technoscience" and I take Heidegger's clear insights into the characteristics of modern physics and modern technology as my starting points. Heidegger's analysis is open to the criticism that it follows the traditional prejudice of equating the foundation of modern science with the foundation of modern physics (neglecting medicine, anatomy, natural history, and chemistry). However, given that I am limiting my discussion to the metaphysical foundations required for the conception of modern experimental physics *as a natural science*, this criticism need not concern me here. Heidegger's characterisation of modern science throughout his work was that modern science is an objectification of Nature that represents "it" in mathematical terms that can not account for the "earthiness" of the world. For Heidegger, modern science, as a theoretical technology, allowed the possibility of producing objects without true individuality (or thinghood). This was itself possible because of the characterisation of knowledge as mathematical projection, the characterisation of scientific investigation as experimental research, and the characterisation of science as an ongoing activity. I shall discuss all three of these characterisations throughout this thesis. This direction of research in experimental physics is driven by an imperative towards the novel and productive disclosure and implementation of mechanisms in novel kinds of machines. The successful implementation of a mechanism in technological practice is taken to be the actual disclosure of those otherwise "invisible" theoretical entities as real entities. These entities are disclosed by theoretical-experimental practices in terms of technologically manipulable and graphically visualisable "natural mechanisms" by which these "invisible entities" interact. The work of novel experimentation is to provide visual representations: intelligible pictures of "the invisible world" that allow the "objects" and "mechanisms" of theories to become "observable" and technologically manipulable. How do these pictures link theoretical and technological practices in experimental physics? Mechanical realism is premised upon a set of precepts. These precepts are:

(i) Natural and technological phenomena both share a unitary origin;

(ii) Both natural processes and machine performances come into being by the same causal principles;

(iii) There is a unique, eternal, and universal cause for every effect (or set of effects);

(iv) The connections between causes and effects are the fundamental mechanisms of Nature;

(v) The realisation of any mechanism is governed by a Natural Law and, consequently, the performativity of machines is governed by the laws of Nature;

(vi) The mathematical descriptions of the motions of mechanical devices, and machines, are mathematical descriptions of the laws of Nature; and,

(vii) The only distinction between natural phenomena and machine performances is that the latter require human intervention to come into being whilst the former do not.

I term these as precepts because they provide principles of action and function as a technical guide for the conceptual establishment of a methodology to explore Nature. I shall discuss how they were used to construct a methodology in chapters two, three, and four. I term these precepts as metaphysical because they provided a unifying conception of "the physical" and were the foundational principles and assumptions justifying the whole enterprise of both experimental physics and modern technology. I shall discuss this throughout.

The metaphysics upon which experimental physics was premised in the sixteenth century has become so widely and deeply accepted that it has ceased to be a metaphysics at all. It has become an inarticulated and habitual set of beliefs, values, and presuppositions, that has been inherited and embodied in both discourse and practice, via processes of educational mimicry and technological enframing. It has become a Kuhnian paradigm or disciplinary matrix. The aim of this thesis is to unmask this inarticulate veil of silence by disclosing the metaphysical foundation of the epistemological legitimacy of the enterprise. The spirit of the enterprise of experimental physics remains concealed until its metaphysical stepping stone has been disclosed. I agree with Nick Maxwell's (1998) argument that physics can not be made intelligible, as a human pursuit, without examining the metaphysical assumptions that are required for evidence and theories to be comprehensible. For Maxwell, science is only possible because of metaphysical assumptions regarding the ultimate nature of the Universe and, echoing Gaston Bachelard, he considered the role of philosophy to be that of revealing these assumptions. Without these assumptions the activities of scientific inquiry would not have any starting points. He termed this as "the fundamental epistemological dilemma of science" (1998, p.4). Physicists are forced to make judgements about the ultimate nature of the Universe from a position of complete ignorance in order to inquire into the nature of objective reality. Hence Maxwell argued that

"Metaphysics determines methodology. This makes it of paramount importance that a good basic metaphysical conjecture is adopted, one that corresponds to how the universe actually is. A bad metaphysical conjecture, hopelessly at odds with the actual nature of the Universe, will lead to the adoption of an entirely inappropriate set of *methods*, and the result will be failure, possibly, of a peculiarly persistent kind." (Maxwell, 1998, p.5)

He proposed a ten level hierarchy of levels of metaphysical assumptions which (1) required that the assumptions implicit in current scientific methodology are made explicit, and (2) ordered these explicated assumptions into increasingly attenuated metaphysical assumptions concerning the comprehensibility and knowability of the Universe. He presumed that once we have arrived at indubitable assumptions (that can not be doubted without impeding the growth of knowledge) then we have a good reason to believe that we are nearing the truth. I wish to put aside the obvious philosophical objections to such a presumption. My contention with Maxwell is that he has presumed that physics is successful from the onset. This presupposition allowed Maxwell to start with "evidence" as the first level of his ten level system. Thus

Maxwell only offered us a system for explicating the assumptions of interpretive (or speculative) metaphysics by using principles of simplicity and comprehensibility. However, Maxwell's system does not provide us with an account of how "evidence" is selected and produced *qua* evidence. He did not provide us with any account of the operational metaphysics that underlies experimental inquiry as a means of producing evidence about the Universe. In my terms, Maxwell's system presupposes mechanical realism as its underlying operational metaphysics. This is required for there to be a level one (labelled by Maxwell as "evidence") on the basis of experiments using machines. It is an implicit "level zero" that allows experiments upon machines to be presented as disclosures of natural mechanisms.

It is my intention to challenge physicists, positivists, scientific realists, and philosophers, to attend to this metaphysics afresh, from within the context of a more general challenge that we all attend to *the phenomenon of making* as an existentially and metaphysically important phenomenon for any inquiry into the conditions and trajectories of the human character. It is crucial in our understanding of what the human character is and how we go about questioning it. This thesis is an attempt to put forward an example of a line of questioning by which we can situate experimental physics into a broader and deeper inquiry into how reality is explored through making. My argument is that experimental physics can be understood as an artificial science (a branch of mathematical engineering) if we understand its essence, and its metaphysical heritage, as an art questioning into its own possibilities by making them happen. This understanding is based upon a phenomenological questioning of the hitherto neglected essence of the artificial in experimental physics. This neglect has led to a false dichotomy: the debate has been restricted to *either* anti-realist *or* scientific realist interpretations of physics. The knowledge produced through experimental physics is supposedly *either* of human origin *or* it discloses pre-scientific structures of the natural world. The argument of this thesis is that we can not sustain an intelligible account of experimental physics if we assume that technology is simply "man made". As a consequence of this assumption, technology is taken to be a simple means to ends and has not been given proper consideration within the realist and sociological accounts of experimental sciences. For the sociologist, only human beings, embedded in social structures, can be causal agents. Scientific change is a product of the struggles between human groups and their interests. For the realist, this cannot account for scientific change because humans *qua* scientists do not control the outcome of their experiments and experimental physics achieves considerable predictive success. There must be a non-human participant, a causal agent which resists and directs human intentions as the thought-independent object of scientific discourse: supposedly the only available candidate is Nature. However, in this thesis, I do not presume that technology is simply "man-made". Sociological accounts need to address both the human and non-human aspects of production as distinct but inextricably inter-related. These accounts either neglect these non-human aspects completely or present them as passive objects utilised according to human purposes. Several sociological writers (including Bruno Latour, Michel Serres, and Isabelle Stengers) have treated the non-human aspects as inanimate material that is moved by social forces into their position on a grid of social networks. I agree with these writers that physics should be understood as a social pursuit in social contexts, but they have adopted a form of social Newtonianism regarding the non-human aspects of reality by considering them as passive materials shaped by the external forces of society. Sociological accounts are necessary but insufficient. An account of the active character of the non-human aspects must be addressed, alongside the accounts of the active character of the human aspects, in order to address the questions of whether physicists know what they are doing, and whether the trajectories and outcomes of experimentation are under human control. In this thesis I shall analyse experimentation as an enframent, an ordering, of intellectual and material practices directed towards production of both machine prototypes for wider exploitation, and also the production of itself as an art. Technology is not completely controlled by human agency but in the context of production, enframes and orders human agency. The non-human participants, the non-human causal agents, in experimental physics, are machines. Thus the knowledge produced in experimental physics emerges from the theoretical interpretation of the performativity of machines. Experimental physics can be understood as an innovative artificial process and that the objects of scientific thought discovered by this process are technologically innovated artifacts. These technological objects are invariant and transcontextural from within the *Ge-stell* set-upon the machines in which the technological objects are connected. They are not completely controlled by human agency, thought, or discourse, because *Ge-stell* is not controlled by human agency. If the objects of scientific reasoning in experimental physics are understood to be artifacts, then experimental physics can be understood as a complex technological process that has been culturally constructed as a natural science. Experimental physics is not completely controlled by human agency nor does it necessarily have anything to do with Nature. This also provides an intelligible non-realist ontology for experimental physics: it is produced but not completely controlled by human agency. The ontology of experimental physics is produced by the cybernetic processes of attempting to theoretically understand technological innovation in terms of the discovery of natural mechanisms. Theorists, such as Andrew Pickering, Donna Haraway, and Michel Serres, have alluded to a posthumanist cybernetic theory of physics, but they have not provided a detailed and intelligible analysis of experimental physics in terms of technological processes. Drawing upon the work of Heidegger, Foucault, Derrida, Deleuze, Lukacs, Merleau-Ponty, Pickering, Serres, Gooding, sociological studies, historical studies, *and experimental physicists*, this thesis will provide a theoretical groundwork for a non-realist theory of experimental physics as a technological phenomenon. This thesis will examine how the contours of human intervention and machine performativity are produced and mathematically inscribed; how these inscriptions are used to produce new machines and novel phenomena; how knowledge is produced through experimentation; and, how that knowledge is related to natural phenomena. I will also address the character of scientific rationality, knowledge, and progress in physics. I shall argue that experimental physics can be understood as a cybernetic process that is presented as a natural science on the basis of hidden metaphysical precepts. I shall discuss the operation of these metaphysical precepts in the mechanics of Moletti and Galileo in chapter two, in the experimental physics of Michael Faraday in chapter three, and how it is presumed by all subsequent experimental physics in chapters four and five. Once the role of mechanical realism has been addressed, from its origins in the work of Moletti and Galileo to the present day, then the conflation of *techne* and *episteme* that lies at the heart of physics can be deconstructed and the ontology of physics can be questioned. In chapter six I shall discuss some implications of this thesis for our understanding of experimental physics, ourselves, and the world-picture of Universe in which we situate ourselves.

Does experimental physics achieve knowledge about the world? Or, to be more precise, what kind of knowledge, if any, do physicists achieve? And, if physicists achieve knowledge, which parts of the world do they achieve knowledge about? In order to address these questions, I will ask the questions: How is experimental physics done in practice? How do these practices produce explanations about natural phenomena? If experimental physics is an artificial process, an art, and the objects of scientific thought are artifacts, then, what do we mean by artifice? How is experimental physics possible? If the experimenters are the shadow-puppeteers who learn their art of puppet-making by watching the shadows on the cave wall change, as they make their shadow-puppets and pull their strings, and I shall argue in this thesis that they are, then what is the fire? What is the fire of the cave? How does it relate to the Sun? And, what is its origin? The philosophers of science have spent too long bound, with the shadow-puppeteers behind them, arguing about what they see in the shadows on the cave wall. They need to turn around, pay close attention to the art of making shadow-puppets, and question how experimental physics is done. How does theory relate to technological practices? How do those technological practices relate to Nature? My argument in this thesis is that the operational metaphysics of mechanical realism is itself an experimental mode of disclosure. The function of this metaphysics is to perform three reductions:

(1) *Ontological reduction.* Only entities (whether described as particles, forces, waves, or whatever) that productively interact with machines, via a mechanism, are taken to be real;
(2) *Methodological reduction.* The study of natural phenomena is reduced to the search for fundamental mechanisms through which such phenomena come into existence and interact; and,
(3) *Epistemological reduction.* The character of scientific knowledge is reduced to "know-how". Thus experimental physics is premised upon the "how does it work?" question and produces answers by attempting to produce and reproduce mechanisms.

The starting point of my argument is a phenomenology of experimental physics. I agree with Heidegger's characterisation of modern physics as a metaphysics of mathematical projection that is bound-up with modern technology. I shall discuss Heidegger's characterisation throughout this thesis. However, I shall be critical of Heidegger for allowing his theoretical preconceptions of *what physics is* to become an obstacle to a deeper inquiry into its essence. I shall argue that Heidegger (despite being highly critical of positivists) had a positivistic conception of the object of experimental inquiry and, as a consequence, neglected the realist spirit of the enterprise. I shall then attempt a "deeper" inquiry than Heidegger did by paying closer attention to this realist spirit and the way that theoretical and technological practices are connected. Heidegger explored how the object of modern metaphysical reflection was determined in relation to a decision regarding *what is* and *the essence of truth*. What interpretation of truth provided the basis for the foundation of modern science and modern technology? What understanding of ontology provided the basis for that interpretation of truth? These are important philosophical questions for any understanding of physics. In his later work, he began an analysis of the metaphysical connection between modern science and modern technology. How are these two phenomena of the modern age connected? Under which metaphysics was the essence of modern science and the essence of modern technology brought together? Heidegger (1977b, p.116) considered the interpretation of modern technology "as the mere application of modern mathematical physical science to *praxis*" to be a misinterpretation. Why is this interpretation a "misinterpretation"? How did this "misinterpretation" arise? I agree with Heidegger that machine technology, as the most visible outgrowth of the essence of modern technology, was not simply "the application" of modern science, but as an autonomous transformation of *praxis*, made demands upon and shaped the form and trajectory of modern science. However, Heidegger did not describe how this happened. Thus he was unclear about how and why it was possible and, consequently, in my view, he equivocated on the connection between modern science and modern technology. Heidegger was correct to characterise both modern science and technology as being bound together, but, by exploring the reasons why he was correct, I hope to achieve a clearer analysis than Heidegger did. I will then be in a better position for criticising scientific realism.

This thesis is critical of scientific realism for two reasons: (i) it is premised upon an uncritical acceptance of the neutrality of technology; (ii) this uncritical acceptance is an obstacle to a deeper understanding of what is involved in making in general and experimentation in particular. I hold a philosophical position is a realist one if it holds that:

(1) What is known to be true would be true independently of whether it was known or not, something may be real without being apparent, objective knowledge is possible;
(2) It is possible that a claim or belief can be false. We are fallible.
(3) Knowledge may be of non-apparent things, mechanisms, or structures, which endure unchanged, even when appearances change.
(4) Knowledge may be of an underlying reality that contradicts appearances.

A realist position is distinct from a scientific realist position. A scientific realist is a realist who holds that knowledge and truth are achieved, or can be achieved, through scientific activities and discourse. It is important to note that a philosophical position can be a realist position without being a scientific realist position. For instance, if one holds the position that science does not achieve knowledge about a "pre-scientific reality" under any circumstances, regardless of whether scientists and certain philosophers of science know that or not, then one is holding a realist position that is anti-realist about science. My position is a realist one, in this respect. I have merely taken on board the fact that scientists, and also certain philosophers of science, try to obtain knowledge. Many "social constructivists" and "relativists" can also be considered to be realists about their anti-realism about science but they often neglect the realist motivations of working scientists. The scientific realist believes that science gives us, or can give us, knowledge of both the observable and the unobservable. S/he argues that indirect evidence, through mathematical and experimental practices, can relate the observable effects of unobservable causes. Such arguments take the form of "inference to the best explanation arguments" – if a theory explains some data better than any other theory, we supposedly have a good reason to think that it is true. Explanatory power is taken to be a reason for belief. It is inherent to scientific realism that science progresses by providing increasingly better explanations. The current scientific explanations may not be true but they are truer than the previous explanations. As Popper put it:

"[scientific realists] not only assume that there is a real world but that also this world is by and large more similar to the way modern theories describe it than to the way superseded theories describe it. On this basis, we can argue that it would be a highly improbable coincidence if a theory like Einstein's could correctly predict very precise measurements not predicted by its predecessors unless there is 'some truth' in it." (1974, pp.1192-3)

In other words, the observable predictive success of Einstein's theory underwrites the existence of unobservable entities it postulates. These entities, such as regions of space-time curvature and invariant metrics, are underwritten by the technological success of using Einstein's theory in the exploratory work of astronomy and physics. The scientific realist argues that if a theory based on unobservable entities produces predictions of observable regularities, and expands the boundaries of what can be observed, then what that theory has to say about the unobservable world has a good chance of being true.

Generally, three criteria identify a philosophical position as being a scientific realist one:

(1) science aims to provide literally true stories about the world;
(2) scientific theories are constructed using potentially literally true and theory independent entities;
(3) the success of our best scientific theories implies that we have a reason to believe that they could be literally true and not just empirically adequate.

Accepting a theory implies accepting all three criteria, it advances our scientific aims, and, therefore, the acceptance of a theory involves the tentative and qualified belief that it is true. Given that we have predictively successful scientific explanatory theories we supposedly have a reason to think of them as true, or at least, approximately true. This kind of argument for a scientific realist interpretation of scientific theory acceptance is an argument for methodological scientific realism.[9] The scientific realist position is, more interestingly in my view, concerned with what science can and cannot do. The scientific realist position expresses the hope that we can transcend human perspectives and achieve knowledge of an ahistorial and asocial quality. Science is to act as a corrective activity upon the social and historical differences in our perceptions of the world into which we are born. Furthermore, science is to take us much further than our limited bodies would otherwise allow. We can extend our powers of observation by using instrumentation. It is this very technological power which supposedly provides us with a wider and more inclusive world view than our inborn nature would provide, and hopefully will provide us with a less relative and more absolute account of the world. This position requires, and maintains, a distinction between the appearance of the world (according to our sensory experience) and the reality of the world

[9] Boyd (1984), Putnam (1973, 1975), and Findlay-Hendry (1995) are examples of variants of this position.

(possibly experienceable through technological powers and scientific exploration). It is this distinction which required the categorisation of the world into primary and secondary qualities or characteristics. Like for Locke and Descartes, this position requires the acceptance of the existence of an absolute, complete world, as it is in itself, to which any particular modes of perception could, in principle, be related. Any such perception would be available to any being of any bodily, cultural, historical and perceptual constitution provided any such being was able to perform scientific activity and thinking. This position, or psychological disposition, is a modern manifestation of the ancient dream that everything in the world can be expressed and known as a universal and eternal principle, or related set of principles. This is an ideal which, at least as of yet, science has been unable to actually achieve, nor demonstrate that it is achievable in the future. The scientific realist's position is one of a faith that science will be able to provide *episteme* even though any "*epistemoi*" so far provided by scientific activity have been short lived and disputable. It is this faith that reveals the extent that scientific realism, as a philosophical position, is based on a psychological disposition. It is this psychological disposition that makes scientific activities and discourses meaningful for scientific realists as being based, if not on knowledge, but on the faith in the possibility of achieving knowledge.

Do scientists need to be scientific realists? Does a scientist who adopts scientific realism behave differently from one who does not? For Findlay-Hendry (1995) the answer to both these questions was an emphatic "yes". His opinion was based on the argument that scientific realism seeks a literal understanding of past and present theories, and the use of concepts underwrites their employment in the construction of *new* theories. He argued that *new* theories point out - and explain - *new* phenomena. This achievement is that of Bacon's dream: *new* knowledge offering *new* powers. Findlay-Hendry, like Popper, argued that the predictive success of scientific theories implies that those theories must have "some truth in them". Findlay-Hendry's argument is based on the premises that science is based on scientific realism, and science achieves successes in both prediction and communication. He considered it to be absurd to claim that science could achieve such successes, being based on scientific realism, without achieving some approximation to the truth. Findlay-Hendry, like Popper, Putnam, and Boyd, used instrumentality and intelligibility arguments for truth. Rom Harré (1986) termed this kind of scientific realism to be "policy realism" and affirmed it. Their arguments presupposed that physics is successful. Let us also assume that physics does achieve success in making predictions and achieving new powers. Does it follow from this that we should be scientific realists? In *A Realist Theory of Science* (1975), Roy Bhaskar argued that it does.

Bhaskar is one of the few scientific realists to take experimentation, making, metaphysics, and material practice as central to the endeavour of physics. He stands alongside Ian Hacking, David Gooding, and Andrew Pickering, in this respect; these contemporary writers have paid close attention to the primacy of material practices in experimental work and have examined experimental physics as a form of making. I shall discuss the work of Hacking, Gooding, and Pickering, as well as the work of others, throughout this thesis. Bhaskar declared his intention "to provide a comprehensive alternative to the positivism that has usurped the title of science". (1975, p.8) Bhaskar proposed his transcendental realist theory of experimental science as a third position to stand against both positivism and idealism. He also rejected descriptivist, instrumentalist, and fictionalist interpretations, as positions that are unable to account for the transcontexturality, or transfactuality, of the objects of scientific thought (i.e. theoretical entities, empirical regularities, and scientific laws) nor can they explain how science corrects itself (1975, pp42-3). I agree with Bhaskar that neither idealism nor empiricism can provide an intelligible theory of experimental physics. However, Bhaskar went further than just providing a realist interpretation of experimental physics. He claimed that a realist interpretation of science is *necessary*, if experimental activity is to be intelligible, and that his transcendental realism "is the only position that can do justice to science." (1975, p.26) He claimed that "without such an interpretation it is impossible to sustain the rationality of any scientific growth or change." (1975, p.15) He argued that there is an ontological distinction between scientific laws and patterns of events, and that the core of theory has a conception or a picture of a natural mechanism or structure at work (1975, p.12-26). According to Bhaskar, the constant conjunction (or regular patterns) of events, produced in experiments, can not be considered as a necessary condition for the assumption of the efficacy of a law because, for a scientific realist, a scientific law must exist prior to being actualised within a pattern of events. For example, a scientific realist holds the laws of electromagnetism to be existent prior to, and independently of, Faraday's experiments on electromagnetic phenomena and Maxwell's mathematical formulation of those laws. The purpose of experimentation is to actualise the mechanisms that are governed by those laws; those are prior to, and transcend, the experimental activity that actualises them. Thus, for Bhaskar, the assumption of the efficacy of a law must proceed the attempts to actualise and stabilise a pattern of events if those attempts are to be intelligible. The laying down of a law is basic. I shall discuss how physics has laid down its laws in chapters two and three.

In this thesis I shall provide a non-realist model of experimental physics that is able to account for the transfactuality of scientific objects, and the rationality of scientific growth and change, without making any judgement upon the validity of the metaphysics which is presupposed by scientific realism. In my view, Bhaskar's claims beg the question. It is the concept of the rationality of any scientific growth or change, which is at stake for any scientific realist interpretation to get off the ground. An interpretation of physics is not inherently flawed if it questions, or even rejects, any notion of rational scientific inquiry. Anti-realist arguments can not be criticised on the basis that they do not sustain a concept of scientific rationality. They are designed to undermine such a concept. The onus is upon scientific realists to provide such a concept because without it there is no rational basis for scientific realism. To criticise anti-realist interpretations of science because they do not provide the basis for a scientific realist interpretation is an unreasonable criticism.[10] Bhaskar made such an unreasonable criticism of anti-realist interpretations of experimental

[10] Norris, for example, based his whole critical realist argument against positivist and anti-realist interpretations of quantum mechanics on the premise that anti-realist interpretations of quantum theory must be flawed because they are not realist. Cf. Norris (2000) ch.2, esp. pp. 48-9. In my view, Norris missed the anti-realists' point about the limitations to what physicists can legitimately say on the basis of

science. Furthermore, descriptivist, instrumentalist, and fictionalist interpretations can account for scientific change by locating the structures of change within the structures of social powers. However, once we take technology into account then we can go further than that. I will argue in this thesis that a concept of "bounded technical rationality" sustains a notion of rational scientific growth and change, without requiring any commitment to scientific realism, providing that this concept is understood in the context of its mechanical realist heritage. This provision does not require any commitment to the truth of those precepts, on the part of the non-realist, because we only need to address their function within the establishment of the template for subsequent scientific practices. It does not matter whether these precepts are true or not. All that matters is how they function within the discursive and technological practices of experimental physicists. Bhaskar limited the concept of scientific rationality to be that which presumes scientific realism. This is not necessary for an intelligible account of experimental physics, nor is it sufficient for an intelligible account of scientific rationality. I shall provide an interpretation of rationality in experimental physics that allows technical growth and change, within the productive contexts in which technical choices and selections are made. This does not require the existence (or inexistence) of natural laws or mechanisms as anything more than encodified sets of discursive and technical indices for the interactions between technological objects. When Bhaskar (1975, p.114) claimed that he has presented a basis for "rational principles of action" he actually offered us a pragmatic principle of action that is characteristic of "bounded technical rationality" and a *techne*.

The constant conjunction of events produced in the closed system of experiment can only be taken to be "governed by Natural Law" if we claim that such pragmatic principles are necessary and we have metaphorically substituted "Natural Law" for *techne*. My argument is that physics achieves progress only by extending the variety technological objects at its disposal. I shall discuss how it does this in chapters three, four, and five. It does not provide necessary and sufficient reasons to presuppose that it does, in fact, discover any natural principles that exist *a priori* to the practices of physics. Thus experimental physics can be said to achieve progress only in a context of technological expansion. Contemporary physicists have more techniques, materials, tools, machines, and instruments, at their disposal than seventeenth century physicists did. Furthermore, the contemporary physicists have the recorded efforts of the previous generations of physicists at their disposal. In a technological context, contemporary physicists are able to deal, on an everyday basis, with far more complex, sophisticated, and powerful machines, instruments, techniques, and tools, than the seventeenth century physicist would have been able to imagine. My argument is that it does not immediately follow from this innovative productivity that the contemporary physicist has one more iota of knowledge about Nature than the seventeenth century physicist (or a pre-socratic Greek, for that matter). Whether physics has progressed in epistemic knowledge is the very question at stake. Bhaskar did not establish any argument for a rational dynamic of change. He merely asserted that there is one. He can not provide such an argument — no realist can — because science is

quantum physics if they are to use the results of those experiments to support their discourse. Furthermore, his argument begs the question.

unfinished and we do not have its conclusions at our disposal. It is experimental. Its success is still open to question. It has not achieved its own *techne* and, consequently, physicists do not know what it is that they have done and are doing, if we demand of them that they provide a complete causal account of all their experiments. After all, as Maxwell pointed out, we cannot say that we are nearing the truth, improving our approximations of the truth, until we know what the truth looks like. We can only claim nearness if we have pre-empted the final form of truth. In Lukacs terms, the final form of truth was teleologically posited from the onset of experimental physics. This pre-emption has been utilised by mechanical realists, since Galileo, by assuming that the theoretical interpretation of the successful innovation of any technique to make novel technological power is a step nearer the final truth about Nature. It is also an assumption that there is any such final truth at all. The formula of "success equals nearness to truth" in the context of experimental physics is premised upon a conflation of knowledge with the acceptance of technique. Henceforth, objective truth has been replaced with technological power. Bhaskar has neglected the constructive role of technology in experimental physics and his argument is premised upon this conflation. Consequently his argument is based upon a false ontological dualism between human activity and Nature as the only possible poles of control at work in experimental activity. This leaves Bhaskar open to the following criticisms:

(i) his transcendental argument for realism is circular and is mere assertion;

(ii) his realist interpretation of the rationale of experimental activity is based on the hidden presumption of mechanical realism and thus is an "internal" rationale; and,

(iii) if the constructive role of technology is taken into account then we do not have to assume that either experiments are purely meaningless human constructions or that they must reveal the laws of Nature that exist independently of human activity.

I shall argue that if we take technology into account then we can provide an intelligible non-realist interpretation of experimental physics in which it is neither purely a human construction nor necessarily reveals any laws of Nature. In chapters three and four I shall describe experimental physics as a process of inscribing the interactions between human interventions and machine performativity. These inscriptions are rhetorically and techno-poetically substituted as mechanisms during the analogical processes of modelling. Theories are the metaphorical and abstract representation of those mechanical motions into an interpreted cluster of linguistic, conceptual, and mathematical possibilities. These are creatively and interpretively extended and manipulated by using analogical and metaphorical connections with other theories, models, machine performances, and techniques. Techniques, theories, mathematical functions, and technological objects transfer across the boundaries between experimental machines. This allows the innovation of those machines and provides transfactual connections between members of the same machine-family. This family is a strata of machines that share a common ancestor prototype; each prototype is constructed through trial and error processes of integrating heterogeneous technological objects from other machine-families. Due to the assumption of mechanical realism, the technological is taken to be transparent and the technographic functives are metaphorically presented as abstractions, or representations, of the mechanisms of Nature.

Through metaphorically based rhetorical, poetical, and visual, techniques, emergent through socially mediated communication and argument, these functives can be verbalised, visualised, and conceptualised, within models and theories of the causes in operation in the occurrence of natural phenomena. These mechanical models and theories are subsequently legitimated through a process of successfully implementing these functives and their model-dependent derivatives in the subsequent extension, innovation, and invention, of their associated machine-families, and feeding them back into processes of guided technological innovation. An acceptance of mechanical realism has allowed this techneic innovation of the production of machines and technographe to be epistemologically justified as an epistemic process of the discovery of natural mechanisms and laws. This is how physics progresses.

The non-realist argument of this thesis satisfies Bhaskar's two criteria for the adequacy of an account of experimental science (1975, p.17) because it sustains the idea of knowledge as a produced means of production; and, it sustains the idea of the independent existence and activity of the objects of scientific thought (providing that the phrase "independent existence and activity" is taken to mean that the objects of scientific thought are not entirely mental entities and that they are not entirely controlled by human intentionality). The task of this thesis is to describe this "independence" and the possibility of innovation without presupposing either technological determinism or scientific realism. The objects of scientific thought maintain this independence because they are technological objects and therefore are not entirely discursive, nor completely controlled by human agency. It does not follow from this that they are natural objects in the sense of coming into existence independently of human existence. It does not follow from the fact of the uncontrollable performance of technological objects that they would exist without the technological practices from which they are emergent and implemented. In order to understand technological objects we need to move beyond linear thinking and address the non-linearity of human-machine relationships. I shall discuss this in chapters five and six.

As a technological product, scientific knowledge is a special kind of social product, which has a mechanism (or structure) as its object that is existentially contingent upon human technical activity and phenomenologically independent from human control. A technological object can not exist without the conditions of its production, (which include the inscriptive, discursive, and material practices involved in its production) but its trajectories, once implemented in practice, transcend human control and expectations. The challenge of this thesis is to understand this kind of object without appealing to the "traditional" dualism of categorising it as either "man-made" or "natural". Such objects are not simply "man-made" but, despite their phenomenological reality, they do not independently exist in the realist sense, either. The non-realist interpretation of experimental physics that is being proposed in this thesis satisfies Bhaskar's criterion (1975, p.24) that experimental physics is engaged in "non-spontaneous production of knowledge". I shall address the ways that technological objects are fedback into the processes of experimentation, and the novel extension of the variety of available technological objects. Both technical knowledge and reasoning play guiding roles in the production of technological objects and the processes of technological innovation. I reject Bhaskar's criterion that any interpretation of science must accept "structural and essential realism", which is defined as "the independent existence of causal structures and things (in the intransitive dimension)", if that criterion is premised upon the uncritical presumption that this "intransitive dimension" is Nature. Do we know that Nature is intransitive? I shall argue that the "intransitive dimension" is itself intelligible as a product of the "transitive dimension" of organised, non-linear, productive agency. Intransitivity is existentially contingent upon productive agency but is not controlled by productive agency because the transitive dimension is itself a non-linear process that is not under control. The uncontrollability of technological objects, which is characteristic of their intransitivity, is due to the uncontrollability of the whole process of innovation. Technological objects have degrees of autonomy once they are embodied in productive practices. It is this autonomy that is the "intransitive dimension" and the subject matter of this thesis. My intention is to satisfy all of Bhaskar's structural requirements for a theory of experimental physics and show how the process of experimentation can be made intelligible, without appealing to "Nature" or "Natural Law" as a ground of that process, whilst attending to the "realist spirit" of the efforts of physicists. Provided that technological objects are not presumed to be controlled solely through human agency then we can bring the ontological status of "the intransitive dimension" into question. My argument is that "the intransitive dimension" is emergent from the technological processes of experimental physics, and is only categorised as natural once mechanical realism is assumed. If we do not assume mechanical realism then "the intransitive dimension" is nothing other than an enduring technological trajectory and, despite its phenomenological reality, it is not real in a realist sense.

Bhaskar's claims go too far. His argument only shows that experimental physicists, aiming to discover causal laws, cannot be empiricists or idealists. Nothing else. He presented a false dichotomy: we either have scientific certainty or poetic intuition (1975, p.44). Examining the role of technology in experimental physics prevents the need for this either/or thinking. Technology provides the concrete and material dimensions for experimental physics and the knowledge of these dimensions is *techne*. We do not need to restrict the debate to either laissez-faire humanism or deterministic realism. My interpretation of physics extends this debate to include the nature, significance, and behaviour of machines in terms of a metaphysics of mathematically inscripted human-machine interactions. Once human imagination and metaphysical justification have been culturally embodied in these machinic interactions then the technographical inscriptions can be poetically metaphorised as "Natural Law" and the "book of Nature" can be read from sheets of mathematics and diagrams. By reducing Nature to a set of mechanical causal principles, and technological objects, *episteme* and *techne* have been conflated through the metaphysical precepts of experimental physics since the sixteenth century. It was this conflation that provided physics with a methodology. I shall discuss this in chapter two, three, and four.

My argument in this thesis is that scientific knowledge is a socio-technical ambition and that experimentation is a socio-technical process. Theories are the products of interpretive and mathematical inscriptions of the technological enframent of the interactions between human interventions and machine performances. Each theory is metaphorically connected to a natural process by social imagination, whereas it is technically connected to a family of machines. It is this social imagination that allows machines to act as interface between human beings and an invisible world of hidden natural mechanisms and laws. The operational metaphysics of mechanical realism allows the translation between machine performances and "Nature" to be made in terms of "natural mechanisms". Quantum Electrodynamics (QED) may well have unprecedented predictive success. What does it predict? Its accurate predictions of the magnitude of magnetic dipole moments, for example, are the prediction of how a particular kind of machine should perform. Scientific knowledge is neither "read straight from the natural world" nor "out of the human mind". This is a false dichotomy. Scientific knowledge is the objective of the processes of generalising the transdicted inscriptions of the contours of human-machine interactions into sets and sequences of causal mechanisms, fundamental mechanical entities, their effects, and mechanical interactions. I shall discuss how this has been done in chapter two, three, and four. The performativity of machines is neither entirely dependent upon nor entirely independent from human agency because it is interactional. Performativity arises in the technological contexts of these interactions. The centre of control and causal power lies neither in a "material world" nor in a "human world" but rather occurs during the processes of bringing together diverse agents and attempting to converge and integrate them into a single centre of control and transformative power. I shall discuss this in chapters four and five. It is this project of integration that constitutes the technological context of production. The specific forms of both human interventions and machine performativity are situationally dependent upon this context, and human-machine interactions are shaped by the technological tasks they are set-up to achieve. The significance of these interactions for the human understanding of Nature only occurs through social and cultural mediation, imagination, and consensus. The interaction between the "intransitive dimension" and the "transitive dimension" is emergent from the interaction between heterogeneous technological objects along a teleologically posited trajectory destined by previous efforts, challenges, and expectations. This insight opens up the possibility of interpreting experimental physics as a technological phenomenon. An intelligible non-realist account of experimental physics needs to draw upon both anti-realist and scientific realist interpretations but is not reducible to either.

<u>The Inadequacy of Empirical Adequacy:</u>

In this thesis I shall explore and discuss how experiences are made through experimental physics. Popper presumed that this process of making is guided by theory but did not provide us with a clear account of how theory is used to make experience. Gooding has provided a clear and detailed account of how *both* theory and experience are made through the actions of the experimenter in the case of Faraday's work in constructing electromagnetic phenomena. However, due to the non-mathematical character of Faraday's work, Gooding does not provide us with any account of how mathematics is used within modern experimental physics to construct theory and experience. In order to generalise the discussion of how theories and experiences are constructed through experimental physics we also need to address the roles that mathematics has in this process. I shall discuss the interactions between mathematical, material, and discursive practices, in the contexts of experimental physics, throughout this thesis.

The boundary between the observational and the theoretical is not clear cut – it may change with instrumentation and also with changed intellectual frameworks.[11] A positivistic account of experimental science is restricted to, in Harré's (1986) terms, "realm 1" and "realm 2" beings. The former are perceivable entities, such as mountains, trees, bananas, etc. The latter are entities that can only be perceived through instruments, such as bacteria, the moons of Jupiter, dust mites, etc. The shape of the boundary between "realm 1" and "realm 2" beings is defined by the innovation of instruments such as the microscope and the telescope. The innovation of new instruments led to the growth of "the observable realm". Observation of entities through instruments such as the microscope or telescope is not simply a matter of perception. One must also interpret what one sees. Kuhn (1961) and Feyerabend (1975) argued that observations using such instruments are made from within theoretical frameworks.[12] The interpretation of perception used to construct observations is made using pictures rather than theoretical frameworks. The indirectness of perceptual experience when using such instruments is a serious problem for a positivistic conception of science because the interpretive processes involved on the boundary between "realm 1" and "realm 2" beings using novel instrumentation is not based on empirical and logical propositions. This problem is made worse for the positivist if the development of a new instrument is based on unperceivable mechanisms, "realm 3" beings. The shift in the boundaries between "what might be perceivable using an instrument" and "what is perceivable using an instrument" provides a science based on theories of "realm 3 beings" with an interpretive dimension. The construction and interpretation of instruments such as electron microscopes, x-ray scanners, neutrino detectors, geiger counters, etc., is at best highly problematic for the positivist and at worst is inconceivable. We need to make a distinction between the kinds of reference-act involved in making reference to "realm 1" "realm 2" and "realm 3" beings. In my view, the ontological status of "medium sized dry goods" or "realm 1" beings, such as mugs, tables, horses, cigarettes, etc., that we have a familiar perceptual acquaintance with, is not an interesting philosophical problem for the philosophy of science. The reference to these objects is not of the same kind as making reference to electrons, genes, and electromagnetic waves, etc., because we do not have a perceptual acquaintance with the latter kind of "objects" *at any time or in any context.* We infer their existence on the basis of particular interpretive practices. Pointing at a tree and saying "tree" is not the same type of reference-act as pointing at a test-tube full of gloopy liquid and saying "genes", or pointing at a photograph of slightly curved lines and saying "electron". We make a technically mediated interpretive reference to the electron and make a

[11] A point made by Popper (1975), Feyerabend (1975),Kuhn (1961, 1977), Hacking (1983), Harré (1986), and Gooding (1990)

[12] Popper (1975) also argued that observations are made in the light of theories. Collins (1985) also argued that observations are made from within conceptual frameworks. As Hacking (1983) pointed out, if we take the term theory to refer to a hypothetical, formal, and abstract mathematical and conceptual representations of a wide body of connected phenomena (as Kuhn, Feyerabend, and Popper do) then this claim is overplayed. The term "construal" is a better one. Cf. Gooding (1990) pp. 123-4 and 256. I shall discuss this term in chapter three.

socially mediated perceptual reference to the tree. These are distinct types of reference-act. The everyday perceptual reference-act is not of interest to scientists *qua* scientists whereas the technically mediated interpretive reference-act is. This type of reference act is distinct from technologically augmented perceptual reference-act. The act of looking down a microscope and seeing bacteria, or the act of looking through a telescope and seeing the moons of Jupiter, is not the same kind of reference act as looking at a microscope and seeing a microscope, or looking at a telescope and seeing a telescope. Making reference to "realm 1" beings is a different kind of reference-act to making reference to "realm 2" beings. The latter is both a technologically mediated perceptual reference-act and a technically mediated interpretive reference-act. The latter requires specialised interpretation and training to be able to perceive what is "there". Even if one is a realist about the objects of everyday perceptual reference-acts, or even technologically augmented perceptual/interpretive reference-acts, it does not follow that one should be a realist about the "realm 3" beings of technically mediated interpretive reference-acts. "Realm 1" and "realm 2" beings are part of the lived-world of experience whereas "realm 3" beings are the causal-mechanisms in explanatory accounts of "the unexperienced world that causes the world of experience". I shall not discuss the ontological status of "realm 1" or "realm 2" beings further. The ontological status of "realm 3" beings and their role in the construction of experience in terms of technically mediated interpretive reference-acts will be discussed throughout this thesis. The argument of this thesis is that we do not need to be realists about "realm 3" beings even if the discourses of experimental physics are constructed using technically mediated references to "realm 3" beings and experimental physics is shown to technologically progress.

None of these factors are a problem for a positivism that is critical of experimental science. They are only problems for a positivistic foundation for experimental science. However, positivism does raise some very important problems for scientific realism. For example, there is always the possibility that at the empirical level two different theories can agree but utilise different theoretical entities; this leads the positivists to argue against any necessary relation between predictive success and truth. Scientific theories are far from accurate representations of reality – they are idealisations and abstractions, which focus on particular properties of phenomena under investigation and cases of partial regularity. However, do working physicists operate under this kind of scepticism? It seems that the scientific realist has a case when s/he argues that working scientists tend to take their theories literally. The aim of theorising is not just a matter of achieving empirical accuracy, or predictive success. It is also a matter of explaining the phenomenal world. Positivists, as descendants of Hume's empiricism, reject metaphysics as either nonsense or unverifiable because, by positivistic definition, metaphysics is taken to lack any empirical content. Positivists presume that physics has a logical and empirical character that is divorced from metaphysics. This anti-metaphysical turn can be seen throughout the works of Hume, Mill, Mach, Carnap, Comte, Wittgenstein, and Bas van Fraassen.[13] However, as Popper (1975, p.39 and pp. 312-2) pointed out, scientific laws, as universal laws, cannot be logically reduced to singular statements of experience and,

[13] It can also be seen in the empiricist approaches of sociologists such as Collins (1985), Knorr-Cetina (1981), and Latour (1979, 1987, 1990).

consequently, positivists, by rejecting all metaphysics, must reject all natural sciences that claim to "discover" universal laws. Positivism, by rejecting metaphysics, cannot affirm the physicists' claim to discover or use universal laws of Nature. A positivistic interpretation of physics is a rejection of the validity of such claims and, as a consequence, must reject the epistemological validity of experimental physics. This raises serious problems for positivistic interpretations of physics that claim to be for experimental physics. Furthermore, as Popper conceded (1975, p.206n), various metaphysical beliefs, such as Kepler's neoplatonic harmonics of the geometry of the planetary orbits about the Sun, have lead to significant advances in theory. History provides many examples, such as seventeenth century atomism, that were untestable using the technologies available at the time. In Popper's terms these theories remained metaphysical until the innovation of technological means by which they could be tested. The demarcation between a metaphysical theory and a scientific theory, in these cases, is one of historical accident and yet the role that they played in the development of science was often significant prior to the innovation of the means to test them (Popper, 1975, pp. 277-8). By rejecting metaphysics, positivists have amputated a significant source of scientific speculation. However, metaphysics has a far more central role in experimental physics than Popper would allow. In this thesis, I shall argue that a metaphysics, namely the metaphysics of mechanical realism, has an essential role in constructing the epistemological justification and development of the processes of using mathematically rationalised machines to "discover" the fundamental mechanisms of nature and mathematical natural laws.

Instrumentalism, like positivism, fails to recognise that an important goal of physics is to produce explanatory theories that describe the law-like behaviour of the causal agents that lead to the phenomena of the experienced world. As Popper (1975, p. 61n) pointed out, the motivation to provide causal explanations of the phenomena of the experienced world is irreducible to the practical technological interest in the deduction of predictions. The former is an attempt to satisfy a basic human desire to explain "the world of experience" in terms of a "deeper" world of fundamental principles and causes. The latter is a part of the two-fold process of testing the deductions of theories and is a route by which hitherto unexpected novel phenomena could be discovered. The prediction of possible novel phenomena is an important aspect of theoretical work. It provides existential statements that can be verified by actually finding the predicted entities.[14] The discovery of new phenomena is a much more important motivation for scientists than falsifying theories. Physicists aim to identify, explore, manipulate, describe, *and explain*, the elements of the world that would exist *independently* of human experience. Positivists, in their rejection of both metaphysics and "deep explanations", have rejected the validity of the narrative aspect of scientific theorising. This narrative aspect, as a kind of story telling, is a cultural phenomenon that attempts to situate

[14] Cf. Rom Harré's (1983) policy realism. Note that existential statements cannot be falsified by experience until a search of the entire world has been performed. The importance of the existential aspect of discovery is one that was somewhat neglected by Popper. For example, physicists and astronomers are far more interested in discovering black-holes, instances of gravitational lensing, worm-holes, or a variety of phenomena predicted using the theory of General Relativity, than they are interested in falsifying it.

human beings within a world-picture. In all cultures, human beings have told stories about how the world came to be. This social and psychological phenomenon is an essential part of what it is to be human. The active construction of narrative about identity is, *in essence*, a part of what it is to be human. Scientists *qua* human beings are no different in this respect. Positivists have made a crucial error by rejecting this essential aspect of 'the human character' as scientifically legitimate. Nothing could be legitimate in ongoing novel experiments, on the positivists' account. Although it always remains possible that a scientific explanation may be replaced at some future date with another explanation, this still does not discredit the claim that physicists seek explanations. Even though it may well be an important part of any explanation that it is taken to be (at least tentatively) literally true it is not actually necessary that it is true for it to qualify as an explanation. All that is required is that an explanation is intelligible. This is as true for a physicist as it is for a shaman. The fact that an explanation is intelligible says nothing about its truth. An intelligible explanation may be true or false and still be intelligible. For example, children may well find the Santa Claus story to be an intelligible explanation for the appearance of Christmas presents at the foot of their bed when they wake up. The fact that it is a fiction does not detract from its intelligibility to children, provided it is taken literally. Newton found the corpuscles explanation of light to be intelligible despite the lack of evidence for it. It did not matter whether it fitted the facts of the behaviour of light – its function was to make light intelligible. Intelligibility is also essential any intentional deception to be effective.

This importance of intelligibility for the acceptance of scientific theories cannot be as easily dismissed as van Fraassen (1980) would have us believe. Of course, to some extent theories must "fit the facts" in order to be widely acceptable, but if a theory does not explain "the facts" then it is an unsatisfactory theory. Although the history of physics has witnessed the establishment of numerous "empirical laws", such as Newton's Universal Law of Gravitation, Boyle's Law for Ideal Gases, Ohm's Law of Electrical Resistance, and Ryberg's Empirical Law for Spectral Lines. These laws only suggested that there was a simple relationship at work in complex phenomena. They did not explain why it had that form. Newton found his own law quite unsatisfactory in this respect. Physicists, such as Leibniz, Boltzmann, and Bohr, were driven to find a theory, or model, that not only matched the "empirical laws" but also explained that model in terms of fundamental entities and mechanisms. On this point, I am in agreement with Harré and Madden (1977), when they argued that explanation is essential to the development of scientific theories. Furthermore, given that the content of these explanations are in terms of mechanisms, or "causal powers", then these explanations can take a functional role in scientific reasoning during the construction of further experiments. This gives physics an exploratory and developmental trajectory. This was also argued for by Peirce (1955, p. 330) when he criticised the empiricist assumption that accurate measurement was the central feature of science because, as he put it, "they fall behind the accuracy of bank accounts" and the determination of physical constants was "about on a par with an upholsterer's measurements of carpets and curtains". It can be argued that current accuracy is greater than the nineteenth century of which Peirce wrote, but his point was to question the assumption that accuracy is as important in experiment as it is often made out – science can be done without a great deal of attention being made to achieve accurate measurements.

We may differ about whether an absolute conception of the world is achievable through scientific activity, or even whether we should aim at such a thing as a directional principle. It certainly is questionable whether an absolute conception of the world, even as a directional principle, is necessary for the practice of science. It is conceivable, as at least a possibility, that any regularities uncovered through scientific activity are spatially or temporally dependent and variable. Physical laws could only be valid from within a very small region of the universe. Alternatively, Nancy Cartwright's (1983) suggestion that the laws of physics are approximations and models constructed in accordance with our interests and needs could well be correct. Hume's denial of eternal and universal natural kinds may well be justifiable. We are not in a position to be certain one way or the other. Furthermore, we are not presently in a position to be certain that fundamental accounts between different sciences will be compatible with one another. One thing that we can be certain of is that science has provided us with technologies and some degree of manipulative power that exceeds pre-scientific abilities. Although the question of absolute truths remains controversial, the case that science is able to conform to Bacon's dream, at least as a directional principle, is evidently the case. Although it may well be the case that many working scientists are scientific realists about their science, it is evidently the case that it is not necessary for a scientist to hold this disposition to follow the Baconian imperative. One can be sceptical of an absolute conception of nature but be able to manipulate and control objects with increasing success. One may reject the notion that science takes us to a deep understanding of the structures of the world, that any such understanding is provisionally and contingently true but constantly open to modification and radical change, but be accepting of the ability to provide practical and useful solutions to present problems.

It is fairly uncontentious to claim that most scientists tend to be realists in the sense that they accept that many of the theoretical terms that they use could correspond to real referents that exist independently of their theorising. In order to provide an intelligible account of experimental physics as an alternative to Bhaskar's I shall assume that most physicists are scientific realists. This assumption brings with it an requirement for the account I shall develop in this thesis. It has to be a two-fold account of both the technological success and the explanatory success of physics. Bhaskar argued that empiricism can not sustain the idea of the independent existence and action of the things that are "investigated and discovered by science". Furthermore, if experience is taken to be both definitive and primary then classical empiricism cannot account for how those experiences are related to discourses about unexperienced things. Empiricism can not account for the fact that scientific discourse, in the context of experimentation, is technically constructed in terms of unexperienced entities and mechanisms. Given that in the world outside the laboratory walls, which Bhaskar terms as an open system, is a complex place in which regularly repeated constant conjunctions of events (such as if A then B), required by the positivistic sciences, are uncommon, then a positivistic science would only operate within the circumscribed confines of the closed system. It would not be able to justify the production of any conjunctions of events that it was able to produce because, as empirical regularities, they would not be transferable from the context of production. These empirical regularities could not be presented as the consequences of natural laws. Thus, for Bhaskar, empiricism can not make the practices of experimental sciences intelligible as a pursuit.

The notion of empirical adequacy was central to the scientific epistemology in the constructivist empiricism presented by van Fraassen. Van Fraassen rejected scientific realism and limited scientific ontological commitments to that given as a matter of direct observational experience. The purpose of an adequate scientific theory is to save empirical appearances without any need for a realist ontology or causal-accounts. This involves adopting the traditional empiricist scepticism regarding the existence of an objective Nature and causes (or entities) that are not apparent as actually observable phenomena. Furthermore, he claimed (1980, p.22) that the demand for causal explanations does not play a role in "the scientific enterprise". Allegedly, objective and mind-independent reality is, by definition, beyond the capacities of human understanding and, therefore, the task of producing a complete and correct theory of objective reality is an impossible one.[15] Van Fraassen argued (somewhat inductively) that if past theories have been shown to be empirically inadequate then this provides a good reason to suppose that current theories will be shown to be empirically inadequate in the future. Many theoretical entities, utilised in past theories, have become merely of historical interest whereas the empirical knowledge those theories have produced have often remained. Consider the case of Newtonian absolute space and time. These theoretical entities have been replaced with the Einsteinian relative space-time as a theoretical entity. Yet much of the empirical adequacy, which Newton's theory produced, remains and is also obtainable using Einstein's theory. It is a possibility that Einstein's theory will be in turn replaced with a theory that will use different theoretical entities. Even if we accept that scientific theories are progressing in their empirical accuracy, predictive power, explanatory success, and productivity of new phenomena, this still does not provide us with any certainty that the theories that are being currently used by working scientists will not be replaced by subsequent theories. In fact, this acceptance of the progress of scientific knowledge prohibits any such certainty. As a consequence of this, it follows that not only is there reasonable doubt in the theory-independence of unobservable entities, *in their necessary existence*, but also that there is no pre-requisite for any isomorphism between the structures of a theory and the structures of the object of that theory, for it to be successful at an empirical level.

Van Fraassen adopted the instrumentalist line that the best that physicists could legitimately claim to achieve are empirically adequate descriptions, predictive success, and manipulative control. The physicist should be content to adequately describe phenomenal appearances by producing abstract formalisms and sets of equations that successfully predict observational results. Explanatory causal-accounts amount to nothing more than fictions. Physicists should rest content with saving phenomenal appearances and reject all explanatory causal-accounts, the notion of objective Nature, and claims concerning the existence of unobservable entities. The best that physicists can achieve, according to van Fraassen, is that the evidence suggests, if the evidence is in favour of that theory, that things behave *as if*

[15] For now, I shall put aside the internal contradiction that we are able the make such a final statement about something we are supposedly unable to make any final statements about.

unobservable theoretical entities existed. This does not support any claim that those entities exist. We should not be surprised at the predictive and descriptive successes of current scientific theories. Scientific theories arise through competitive social processes in which only the successful theories emerge. These theories are latched onto observed regularities in Nature (1980, pp.19-40). Nancy Cartwright (1983) made a similar point when she argued that literal representation is not a criterion in theoretical modelling. Assumptions and approximations are accepted which, although not exactly true, are not exactly false either. Theories are corrected and modified in order to fit the facts. She argued that physicists need to simplify complex natural phenomena in order to provide the simplicity appropriate for mathematical description. Thus both theories and the objects to which they apply are constructed and then matched, in a piecemeal fashion, to the real situations. This process sometimes provides predictive accuracy but rarely do theories and models match all the facts at once. She argued that fundamental laws do not, in fact, describe reality but only describe the appearance of reality. This appearance "is far tidier and more readily regimented than reality itself."(1983, p.162) Cartwright argued that reference acts in terms of discrete and stable theoretical entities occur through attempts to simplify complex real phenomena. Physicists can only achieve abstract descriptions of "the appearance of reality" and these are insufficient to provide good reasons for a belief in the theoretical entities used to produce those descriptions.

My first criticism of empirical approaches to modern physics is that it is a mistake to claim that the theories of modern physics represent "the world of experience" or "the appearance of reality".[16] The "world of experience" is not "the objective world" explored by modern experimental physics.[17] Although "the world of experience" and "the objective world" are both parts of the same world neither are reducible to the other. The empiricist misrepresents the object of inquiry for modern physics. The "world of our experience" contains phenomena such as blue skies on clear summertime days. How would a physicist describe such a phenomenon? How would a physicist describe the colour blue to someone who had been blind since birth? Let us assume that the blind person is conversant in the language of modern physics. The physicist could describe the eye in terms of an optical device. S/he could describe how electromagnetic waves of a particular wavelength radiate from the Sun, are refracted and scattered by particles in the Earth's atmosphere, are focussed onto the retina by the lens of the eye, stimulate the rods and the cones of the retina, and are transformed into electromagnetic pulses in the optic nerves. S/he could then describe how these electromagnetic pulses travel through the optic nerves, travel through a network of nerves leading to the brain, generate electrochemical process in the brain's network of neurons, and are finally 'processed' by the brain as the colour blue. Let us assume that whatever theory, or model, that the physicist utters is empirically adequate to the extent that its derivative resultant would be that the sky on a clear day would

[16] This is a mistake made by classical empiricists, logical positivists, van Fraassen, and Popper (Cf. 1975, p.39).

[17] This point was made by Merleau-Ponty (1999, p.3) in his criticisms of intellectualist and empiricist accounts of perception. Heidegger (1962) also made this point with regard to attempts to equate lived spatiality and temporality to any scientific conception of space and time.

have the colour blue. Let us also assume that the blind person perfectly understands the physicist's description of how the eye and brain processes differences in wavelength. But does the blind person know, on the basis of this description, what an experience of the colour blue is? There is one essential characteristic of the colour blue that is missing from the physicist's description of blue. That essential characteristic is the *blueness* of the clear daytime sky. It is a quality of clear daytime sky that is immediately experienced by all people who are able to see it. One merely points at the sky on a clear day and remarks on its blueness. The blind person will, from the physicist's description, have no idea whatsoever of the experience of seeing the colour blue. Nor will the blind person have any idea, from the physicist's description, that there is even the possibility of the experience of blueness. The physicist could talk of atoms, electrons, photons, matter, ions, radiation, wavelengths, refraction, the spectrum, prisms, electromagnetism, oscillations, coupling-constants, or resonance, but would be unable to introduce blueness into her/his description. The blind person would have no more idea of the experience of looking at the sky and seeing its blueness, as a result of the physicist's description, than s/he did at the onset. The physicist could deny the facticity of the blueness of the sky on a clear day to people who can see the colour blue. However, any arguments against the facticity of the blueness of the clear daytime sky require assumptions and premises that would be more suspect than the indubitable experience of blueness. Blueness remains *surplus* to the physicist's descriptions of the colour blue. It lies outside the language of physics and remains an undeniable *residua* to any attempt to explain it away. The same is also true of all the qualia that are characteristic of "the world of experience" or "the appearance of reality".[18] The lived-world of human experience contains surplus and residua qualia that cannot be reduced to the language of physics. The language of physics is essentially reductionistic and operates upon a distinction between primary and secondary qualities.

The primary qualities are taken to be qualities, such a number, size, weight, volume, etc., which supposedly do not vary between human subjects. These are taken to be the properties of objects. The secondary qualities are taken to be qualities, such as colour, scent, value, orientation, meaning, etc., which vary between human subjects. These are taken to be the properties of the reaction of human subjects to objects. Primary qualities supposedly allow for an universalisation of description that the secondary qualities do not. If this is accepted then any description of the world that is presented as an universal description can only include primary qualities and all secondary qualities, no matter how remarkable they might be, must be excluded. Descriptions of the phenomena of "the world of experience" must be reduced to include only the primary qualities if those descriptions are to be universal descriptions. As these universal descriptions are taken to be descriptions of the properties of objects then such a description would be a description of "the objective world". The language of physics is disciplined reduction all that could be said to include only that which could be said by all. As the descriptions of "the objective world" are not limited to any particular human observer then "the objective world" is taken to be independent of all human observers. "The world of experience" includes experiences of both "the objective world" and "the

[18] This point was also made by Dunne (1948, pp. 11-7).

subjective world". None of these "worlds" are reducible to one another once the distinction between primary and secondary qualities has been made.[19] Physicists aim to identify and describe the elements of the world that would exist *independently* of human experience. Physicists only study "the objective world" and do not study whole world. From the very onset, physics excludes all characteristics that are taken to be dependent upon human experience.[20] Physics excludes human beings from its object of study; it also excludes itself. Physics is expressly the study of those elements of the world that would *supposedly* remain if there were no human beings to experience them or their effects. As such, physics is implicitly an attempt to obtain objective knowledge and is a realist enterprise.

Physics is not primarily the study of everyday objects. The directly observable objective behaviour of familiar objects, such as trees, rocks, nuts, berries, and bananas, are of little interest to the experimental physicist. Studies of the behaviour of familiar objects, at most, constitute starting points for experimental physics. The observation of the empirical regularity that hot objects, in a cooler environment, cool down, and cold objects, in a warmer environment, warm up, (formally universalised as the Zeroeth Law of Thermodynamics) constitutes an almost trivial starting point for the study of thermodynamics. The physicist wants to know why this empirical regularity occurs. There is a big leap from this "empirical regularity" and an interpretation of it in terms of flowing heat. An even greater leap is required to quantify heat and construct an apparatus to measure the conservation of that heat flow. On van Fraassens' account, it is hard to see how thermodynamics could have progressed from the Zeroeth to the First Law. The Second Law, with its esoteric definitions of work and entropy, could not be part of "the scientific enterprise", without an appeal to theory. The majority of experimental work in experimental physics involves the investigation of phenomena of which we have no direct experience whatsoever. We do not have direct experience of the majority of the phenomena investigated by the studies of mechanics, thermodynamics, electromagnetism, radioactivity, solid state physics, or quantum physics. The study of these kinds of phenomena involves the interpretation of the performances of machines and instruments. We only have experience of the numerical and analogue readings on calibrated meters, oscilloscopes, graph plotters, gauges, computer displays, and other instruments. However, these experiences are not direct sensory experiences. We need the mediation of technical education before we can make sense of our direct sensory experiences of instruments. Each instrument is calibrated using technical entities (such as potential difference, time-signals, inductance, capacitance, thermal capacity, electrical resistance, phase, frequency, mass, magnetic field strength, force, harmonics, electric charge, power, etc.,) quantified in terms of arbitrary SI units (such as kilograms, metres, candelas, seconds, amperes, moles, radians, kelvins, newtons, coulombs, tesla, watts, etc.) These technical entities and units are meaningless outside of the theoretical and

[19] Cf. Nagel (1986) for a discussion of some of the problems this causes for realism and objectivity

[20] Although it is questionable whether qualia, such as blueness, should (or could) be properly categorised as subjective, intersubjective, transcendental, epiphenomenal, or whatever, the claim that they are, at least in part, existentially dependent on the existence of a being capable of experiencing them is a relatively uncontentious one.

technological frameworks in which they occur. By claiming that measurement using such instruments provides direct experience, the empiricist merely has passively accepted the stable results of an historical struggle of technological and theoretical efforts, and the current state of instrumentation, education, and interpretation as givens. The empiricist has neglected the role that theories and causal-accounts, involving theoretical and technical entities, have had in the construction of those instruments and their interpretation. If we were to describe the objects of investigation and theories as fictions, as does van Fraassen, that are instrumentally used to interpret the empirical facts of measurement, we would still require interpretive and theoretical training in order to ascertain what the empirical facts of measurement were (in all but the most trivial of experiments.)

Entities such as potential differences are no more, nor less, fictional than entities such as electromagnetic fields, given the fact that we have no direct experience of either and both are only meaningful within theoretical interpretations. The former are only considered to be more concrete than the latter on the basis of a passive and uncritical acceptance of past theoretical interpretations and an arbitrary scepticism about present theoretical interpretations. If we were to consistently adopt van Fraassen's empiricism then experimental physics would be a process of instrumentally using fictional entities to investigate other fictional entities. If a final complete description of "the objective world" is impossible then it would be pointless to map out the empirical variation of the fictional entities used to make instruments intelligible against the fictional entities used to make theories intelligible. The empirical adequacy of any laws that would be produced through such a process would be the pointless inter-relation of different kinds of fictional entities. Modern experimental physics could not be grounded on "constructive empiricism" and physicists would not rest content with it. Modern experimental physics is not empirical in the philosophical sense; a physicist does not rely upon direct experience but investigates the disclosure of interpreted instrumentation to direct experience.[21] An intelligible account of physics must provide an account of how this disclosure is possible and how it is achieved. Empiricists cannot provide us with an account of how observations of using instruments are obtained because they cannot consider the technical reasoning (made in terms of theoretical entities and causal-accounts) used in the interpretation of measuring instruments and experimental apparatus, as scientific. Thus they either cannot provide a meaningful account of observation within experimental physics in terms of scientific facts, or it is only able to provide accounts of observation by arbitrarily, passively, and uncritically accepting particular technical interpretations of particular measuring devices as given. Causal-accounts, in terms of theoretical entities and mechanisms, are central to the interpretation of experimental apparatus and measuring instruments. Any causal-account is, at least in part, an explanation. Modern experimental physics could not proceed without them.

Experimental physics provides descriptions of entities, properties, and mechanisms, of which we do not have direct experience (such as mass, charge, fields, radiation, atoms, virtual particles, coupling constants, etc.,) in terms (such as number, rate of change, magnitude, proportion, direction, etc.,) that can

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[21] Feibleman (1982, p.6) also made this point.

be related to mathematical practices, interpretations, and technological manipulations using measuring instruments and experimental apparatus. It is limited to descriptions of an objective world of machine performances in terms of laws, causes, unperceivable entities, and mechanisms. The descriptions produced by modern physics make reference to and utilise what Harré termed as "realm 3 beings". Experimental physicists, whether or not they realise it, tend to be scientific realists. The theories of modern physics attempt to represent "the unexperienced world that *causes* the world of experience" and not "the world of experience". It attempts this by interpreting "the objective world" of machine performativity in terms of "realm 3 beings". Measuring instruments and experimental apparatus are the "the objective world" interface between "world of experience" and "the unexperienced world that *causes* the world of experience". This interface is interpreted using technical causal-accounts in terms of "realm 3 beings". Van Fraassen's *a priori* rejection of the role that such interpretive technical causal-accounts play in "the scientific enterprise" of modern experimental physics prevented him from producing an intelligible account of experimental physics. He also attempted to close off the character of "the objective world", that is explored through physics, from philosophical analysis. It is the phenomenological character and ontological status of "the objective world", explored through physics, that is the subject matter of this thesis. In order to question the ontological status of this world we need to examine the complex relationships that occur, through the interface of measuring instruments and experimental apparatus, between "world of experience" and "the unexperienced world that *causes* the world of experience". How is "the objective world" used to disclose "the unexperienced world that *causes* the world of experience"? We need to examine experimental physics as a scientific realist enterprise of disclosing the "the unexperienced world that *causes* the world of experience" through kinds of human interaction with machines.

Van Fraassen assumed a robust and clear distinction between theory and observation that is not apparent in actual experimental work. Observations occur in the light of theories, within theoretical frameworks or paradigms, using concepts, visualisations and construals.[22] The processes of making observations are socially mediated interpretive and interactive acts. They involve making choices and judgements that are irreducible to either empirical or logical propositions. Experimentation is based on planned action, selections, and decisions.[23] It is not based upon a passive reading off facts from the world but is a process of active intervention.[24] It is an interpretive, interventional, and interactive process in which *experiences are made* through deliberated interpretive and material practices rather than passively received. Positivism is unable to deal with the processes of constructing novel experiences of novel phenomena. It is unable to account for the ways that novel material, communication, and visualisation practices are constructed when dealing with novel phenomena.[25] Positivism cannot provide an account of how theories

[22] Kuhn (1961, 1977); Popper (1975); Feyerabend (1975); Collins (1983); Gooding (1990).

[23] Gooding (1990); Popper (1975, p. 280)

[24] Hacking (1983); Gooding (1990).

[25] Gooding (1990, pp. 29-30) made this point in his discussion of the construction of novel communicable experiences in the early work on electromagnetism by Faraday *et al.*

and their tests are to be constructed in the face of novel phenomena. Nor can it provide an account about how novel experiments can be constructed in the absence of an established theory. Novel experimental research programs could not proceed according to a rigid positivistic conception. Bhaskar (1975, p.167) was right to argue that there are not any general philosophical criteria for judgements of adequacy of an empirical law because such judgements are intrinsic to the sciences concerned. The criteria for judgements in chemistry will not be the same as for psychology, nor would those for genetics be the same as for physics. Judgements of adequacy are also based upon aesthetic estimations of technical excellence, utility, simplicity, etc. Adequacy is determined in context, through use, experience, and expectations. Such judgements are made in relation to other people and the historically transitional standards for adequacy, which are used to make experiences commensurable within the same historical period. It is whiggish to compare the efforts of medieval mechanists with twentieth century mechanical engineers on the basis of an affirmation of the standards of the latter as an improvement. This respect for the efforts of the past has been accepted in science studies since Kuhn wrote *The Structure of Scientific Revolutions*.

Furthermore, by asserting that sensory observation founds all genuine knowledge, by presuming that only those statements that are derived from experience are legitimate or scientific, the positivist has neglected to attend to the ways that experience is itself constructed. The positivist, by considering the problems of traditional philosophy as metaphysical pseudo-problems that are meaningless for empirical sciences, has neglected the fact that the central problem for traditional philosophy has always been a *critical analysis* of appeals to the authority of "experience".[26] Positivism, by uncritically making its appeals to "the authority of scientific experience", rests upon a reactionary and conservative appeal to already completed scientific results. It is unable to account for the construction of experiences in cases of neither novel experimental physics, nor the impact that those novel experiences have in the subsequent construction of novel theories, and is only able to provide a conception of experimental physics during its Kuhnian "normal science" phase. It fails to recognise the explorational, speculative, and constructive processes of experimental work. By reducing physics to the systematic ordering of our sensory experiences, positivism restricts "facts" to be statements of our immediate experiences made in terms of already given language. Thus it is impossible for us to add any fact that cannot be expressed and logically analysed in terms of already given language. It is impossible for positivists to explain how novel experiences could be constructed in terms of novel language because the restriction that they place upon legitimacy and intelligibility would not allow the processes involved in the construction of novel language to begin. Any novel experiment would be unscientific according to the positivist conception of science. Thus positivism cannot account for scientific change nor can it account for how experimental physics began in the first place.

Hacking (1983) also argued that the growth of the observable realm through instruments is an important feature of science. If the same entities can be observed with independent instruments then there is a good reason to believe that they exist independently of those instruments. This belief in the

[26] A point made by Popper (1975, p.51-2)

transcontexturality (or transfactuality) of the existence of theoretical entities, such as electrons or electromagnetic fields, is central to the "internal" intelligibility of experimental physics as a pursuit and emphasises the importance of cross checking. This point was also central to Rom Harré's and Bhaskar's arguments for scientific realism. Positivism cannot justify a belief in the transcontexturality of theoretical entities because, by limiting knowledge to the empirical, it is unable to legitimately transcend the particularity of experience. Theories are nothing more than a means for the logical deduction of predictable events. Instrumentalism, a descendent of positivism, proposes that a theory is nothing more than a tool or an instrument for prediction and control. For the instrumentalist, there is no distinction between science and technology. Science is a technology, an instrument, to produce predictive power and control. Choice between theories is made on the basis of the empirical adequacy and/or instrumentality between them rather than their truth-status. On an instrumentalist view, it is possible for statements about a kind of entity to be logically consistent and useful despite the fact that the kind of entity in question does not exist. An example would be an ideal gas. Statements about the properties of an ideal gas can be logically consistent and useful despite the fact that an ideal gas is an imaginary entity. Mach, Schlick, and van Fraassen, are exponents of varieties of instrumentalism. There is much commonality between the interpretations of science expressed by the instrumentalists and that of Dewey's pragmatism. Theories, according to instrumentalists, are merely instruments to provide predictive success and manipulative control. Any theoretical entities, such as electrons or electromagnetic fields, are *fictional* and should not be taken to be literally real entities. Van Fraassen inductively assumes that because past scientific theories have been falsified and replaced there are good reasons to assume that current theories will, in turn, be falsified and replaced. Theories, on his account, should be treated as fictions and not as literally true. The central problem with instrumentalism is that it is unable to explain how these instrumental theories based upon fictional entities can provide predictive success and facilitate manipulative control at all. If electrons and photons are merely fictional entities then how can instrumentalism explain the incredible predictive accuracy of Quantum Electrodynamics? Furthermore, if the validity of any theoretical entity is restricted to its utility then such entity could only be said, by an instrumentalist, to operate within the context of use. Thus theoretical entities do not have any transcontexturality. When physicists experiment on electrons in electric circuits they are not operating with the same kind of electrons as the physicists at CERN. The instrumentalist is unable to explain how these physicists are able to use the same theories, say QED or Maxwell's equations, in these distinct contexts. Nor is the instrumentalist able to account for the physicists' motivation to perform the experiments in the first place.[27] If the theories produced by experimental work do not refer to anything outside the contexts of the experiment then either physicists do not aim at obtaining universal laws or they are deluded. Given that theories such as Maxwell's equations are taken by physicists to apply to *all* electromagnetic phenomena, and QED is taken to apply to *all* electron-photon interactions, then, on the

[27] Norris (2000) made this point in his criticisms of both the positivistic and anti-realist interpretations of quantum mechanics.

instrumentalist account, physicists must be deluded. On the instrumentalist account, the apparent transcontexturality of Maxwell's equations and QED must be merely co-incidental. However, as I shall argue in this thesis, the transcontexturality of techniques, theoretical entities, mathematical practices, instruments, and theories, is essential to the construction of experiments, the innovation of technologies, and the development of physics. We do not need to deny transcontexturality in order to criticise scientific realism. Furthermore, instrumentalism can not provide an account of how physicists fail to successfully perform experiments. Given that Morpurgo's experiment to attempt to find free-quarks was a project that utilised fictional entities, electrons and electromagnetic fields, to attempt to find other fictional entities, namely free-quarks, then there does not seem to be any source of resistance to its success. If what constituted the proper use and identity of theoretical entities is completely determined in context then there is nothing to prevent a physicist, in that context, from achieving success. One need only instrumentally reconstruct the meaning of the performativity of the apparatus according to one's intentions within that context. Other physicists, in other contexts could not object to this because one could merely argue that they were using the terms "electron", "electromagnetic field", and "free-quark", differently within different contexts, and that anyone who failed to repeat the observation merely had failed to re-construct the context of use. Instrumentalism does not provide an intelligible non-realist account of experimental physics. An intelligible non-realist account of experimental physics must provide an account of how theories can be predictively (un)successful and are used for manipulative control (well or badly). It must also provide an account of how theoretical entities achieve transcontexturality.

Empiricism can not provide an account of the 'feedback' processes between scientific theories and the construction of experiments, and experience. It is unable to do this because it is premised upon completed knowledge, reasoning, techniques, experiments, and experiences. It is unable to cope with novel (or revolutionary) experiments and cannot explain how and why experiments were constructed in particular ways. Empiricism can not explain how theoretical entities "transcend" neither the particular contexts of their production nor how predictive success is possible. Classical empiricism fails because the technological environment of the laboratory is unintelligible to primitive experience. Scientific instrumentation is a meaningless maelstrom of flashing lights, moving pointers, digital displays, graphs, and readouts, to the uninitiated. Technological discourse is required to construct a meaningful experience of experimental apparatus and instruments. There is nothing primitive about voltages, time signals, amplitudes, temperatures, and pressures. Furthermore, if we accept that the production of causal-accounts is an essential aim of experimental physics, then positivism, by rejecting the possibility of the knowledge of causes, cannot provide an intelligible account of how and why novel experiments are constructed and performed. A physicist uses causal-accounts to construct an apparatus that relates variables. S/he cannot operate experimentally by restricting the technological discourse to the level of "when substance A is placed near the geiger-counter the current across the tube increases by B" when designing the experiment in the first place. S/he utilises a discourse at the level of "if radioactive material emits energy sufficient to ionise a gas then this will be manifested as a current across a sealed tube with a voltage across it. Therefore we can build a device to measure levels of radiation." The capacity of physicists to construct experiments is dependent upon such causal accounts. Even if we constrain "the world of experience" to the confines of the laboratory, as orthodox empirical accounts of science have done, as a means to verify or falsify theories by testing their predictions and deductions, this still does not provide us with an account of how those experiments are constructed. Empiricism tends to only account for experimentation in terms of a ready-made procedure of measurement, without any justification of that procedure, because it has neglected to attend to the role of technology in experimentation. As Heidegger, Rom Harré, Hacking, Bhaskar, and Gooding have pointed out, because empiricism (and positivism) can only deal with Kuhnian "normal science" it cannot account for novel physics.

However, scientific realism has also neglected the role that technology has in the construction of scientific theories. Consequently it has presumed that the causal accounts produced by the experimental sciences must refer to natural causes. Hence, there is a false dichotomy between positivism and realism presented in Bhaskar's argument: if positivism fails to provide an adequate theory of science then realism is the only alternative. However, if we address the constructive role of technology in the production of scientific theories then we can examine scientific causal accounts without committing ourselves to either a realist or positivist interpretation of them. If scientific causal accounts are neither fictions nor refer to natural entities then Bhaskar's dichotomy is a false one. We are not compelled to consider scientific causal accounts to be either fictions or referent to natural entities. The causal accounts utilised by physicists are techneic guides to the construction of machines and their associated theories. These techneic discourses are constructed in terms of the first causal principles, or mechanisms, that are in operation during the interaction between human intervention and machine performativity. Such discourses only require the existence of particular kinds of machine and particular modes of technological activity. They do not need to refer to Nature at all. Bhaskar has neglected to attend to how physicists actually test statements about causes. What physicists actually do is attempt to embody such statements into their practices of designing, constructing, operating, and interpreting, machines. They embody causal statements by transforming them into machinable forms. It is only by making such a process neutral and transparent, through social processes and metaphysical precepts, that the transformative nature of technological embodiment can be conveniently forgotten. I shall discuss this in chapters five and six.

However, when Bhaskar claimed (1975, pp.33-7) that the empiricists have conflated ontology and epistemology he has misrepresented their point. The empiricists' point is not that human experience is an existential condition for the existence of the world, but, rather, that what we can legitimately say about the world is <u>limited</u> by what we know about that world based on experience. The empiricist has conflated ontology and epistemology only in the sense that the study of being is constrained by empirical knowledge. It has epistemologically enframed ontology. Hume, for instance, did not claim that "what is" is itself constrained by "what is experienced". His claim was that talk about "what is" outside of "what is experienced" is mere speculation. The empiricist does not place any restriction upon what does exist; s/he places a restriction upon what we can <u>say</u> about what exists. For the empiricist, a statement about cause is an assertion of belief, or an expression of speculation, and is not an example of knowledge. The epistemological point made by empiricists is that knowledge should be prior to discourse about things. The "empirical world" is the part of the world that the empiricist claims that we can have legitimate knowledge about. This only places a constraint upon which part of the world we can claim knowledge about. Empiricism only places a constraint upon discourse. It does not place any constraint upon the world and Bhaskar has misrepresented empiricism by claiming that it does. However, empiricism does not provide an epistemology that provides a meaningful account of the spirit of experimental physics. Bhaskar was right about this. Hume's critique would not support experimental physics as a route to knowledge. Bhaskar is right about this too. However, Bhaskar (1975, p.40) misrepresented Hume's position by claiming that Hume assigned impressions an ontological primacy. What Hume did was to assign impressions an epistemological primacy and consequently all knowledge (not being) must begin with impressions. This only constrains ontological discourse and does not constrain being. Hume did not conflate knowledge and being. He constrained knowledge claims about beings. His point was that experience <u>should</u> constrain knowledge about the world and <u>not</u> that it constitutes the world. Hume refused to make knowledge claims about an unexperienced world. Hume's point was that events are often co-joined, i.e. heat and flame, a heavy object falls when dropped, thunder and lightning, etc., but we cannot have certain knowledge about any causal connection between them. He did not deny that causal connections exist. Hume's concern was about the knowledge claims that we make based on the use of reason. He did not make any claim that the world was comprised only of events; he argued that our experience of the world was comprised of events. His point was that "necessary causes" were beyond our experience and that, if we base our knowledge upon experience instead of reason alone, we cannot claim to have any knowledge of "necessary causes". Hume equated knowledge with the empirical; he did not equate the real with the empirical.

Bhaskar (1975, p.32) asserted that events are "categorically independent of experience" and rejected the empirical definition of events in terms of experience. However, in relativistic and quantum physics observational acts are required for an event to be determined. This does not necessarily involve direct perceptual experience on the part of a human being, and is certainly not subjective (an accepted technique of measurement is required), but it does require measurement. An event is determined from within technological enframent to the extent that the phenomenon in question is reconstructed in terms of a set of measurements. The observational experience is reduced to this set of measurements. Thus events and experiences are categorically brought together by technology. They can only be taken as independent by making the technology involved transparent. Reference to an unperceived object (e.g. radioactivity) is made via the connection between theoretical discourse and technical discourse, as a distinct kind of reference act to a perceived object (e.g. the clicks of a geiger counter). Bhaskar's realism treats these two kinds of reference act as if they were the same kind because he assumes a tight and competent link between scientific interpretation and perception. He has uncritically accepted the technical expertise of scientists. So did Hacking. However, this assumption is inconsistent with both of their theories of science. If one accepts that our knowledge of the intransitive objects of perception is itself transitive, as Bhaskar does, then we cannot assume that there is a tight and competent link between any perception and any interpretation of that perception. If our interpretations change, which Bhaskar accepts, and our skill at making interpretations improves, which Bhaskar asserts, then we cannot, at any stage, assume that our current interpretations are correct and, therefore, we must maintain a distinction between the two types of reference act. Van Fraassen was quite right to maintain this distinction. Bhaskar made an argument of the kind that he rejected as illicit when he argued (1975, p.32) that it follows "from the current state of knowledge we can... state that there were events unperceived and unimagined by previous human beings, in the past, and that (1) these events actually occurred in the past; (2) these events were possible in the past; (3) these events occur independently of our current productive capacities". The act of interpreting the past in terms of current interpretive and perceptual reference acts is an act of reconstruction. It reconstructs the past in terms that are only presently available. We need to be sensitive about the reconstructive character of our efforts to interpret the past. Aristotle was mistaken when he claimed that we do not deliberate about the past. It can be changed by political action, as Lukacs and Orwell pointed out. It is only as a result of such a reconstruction that we can postulate the past existence of events that were unknown and unperceived at the time they occurred. Events that are unknowable and unperceivable, if they occur at all, would never be a part of science unless there was a change between the boundaries between "unknowable" and "unknown", and also between "unperceivable" and "unperceived". As Harré (1983) and Don Ihde (1991) pointed out, the distinctions between "unknowable and unknown" and between "unperceivable and unperceived" are crossed by technologies, such as the telescope, the microscope, the electron-microscope, etc. The problem for the empiricist is not whether or not such events existed but, rather, is how can knowledge of such past events be constructed given that they were unexperienced in the past. Whose experiences do we use? The empiricist does not claim that the set of unknowable and unperceivable events is empty, as Bhaskar claimed (1975, p.32) they must. For the empiricist, there is nothing that can be said, based on knowledge and perception, about the contents of such a set. On that point, I agree with the empiricist.

Bhaskar suggested (1975, p.34) that transfactual Laws of Nature must exist because experimentalists can make mistakes. I agree that mistakes can be made but disagree that the facticity of "Laws of Nature" follows from this. All that need follow from human fallibility is that there are expectations, and ends, and the possibility of satisfying them, or not. We also have changing standards of success between different groups of people and different periods of time. Failure says nothing about the ontological status of the "Laws of Nature". Nor does it follow from fallibility that the means of satisfying expectations are determined by any kind of law (natural or otherwise). Nature, if involved at all, may well have whims. My argument is that if we treat technology as heterogeneous then failures are the result of incompleteness, complexity, and diversity between non-linear processes, rather than a failure of correspondence. Bhaskar's transcendental realist ontology depends on a reified technocentricity and a concealed metaphysics. Bhaskar described his position as one of "nature-centricity". This is only the case if "nature" is taken to be that which is revealed by the technologies of experimental physics. His claim to maintain a "nature-centricity" is a form of anthropocircumferentialism[28] based upon a conception of "technical man" as a natural being. In my view, Bhaskar (1975, p.58) misrepresented empiricism by claiming that "the concept of the empirical world is anthropocentric". The concept of the empirical world would only be anthropocentric if it also implied that human beings were the origin and controller of experience. Empiricism cannot make any claim to the knowledge of the origin of experience because that would lie outside (prior) to experience. This is one of the crucial distinctions between Hume and Kant. Empiricism makes a modest claim to limited human powers to know the world that rejects the more grandiose claims to knowledge of the world make by practitioners of speculative reason. In this respect, transcendental realism represents a far more a concealed "anthropocentric" ontology that the empiricist would allow because it presents, as I shall argue in this thesis, a human created view of the world as the world itself. Bhaskar (1975, p.35) misrepresented empiricism by claiming that it commits "the epistemic fallacy". It is true that empiricism is primarily concerned with epistemology over ontology. However, the primary concern of empiricism is to find justifications for a distinction between certainty and speculation. For empiricists, we can be certain about constant conjunctions but only speculative about causal laws. Their mistake is to presume that the "we" is well defined and speculation is technically functionless. If empiricism mischaracterises science it does so by placing prohibitions upon the speculative reasoning that is central to scientific exploration. Science could not exist without speculative reasoning. However, it does not follow from the fact that science speculates upon causal laws that these laws exist outside of, or prior to, scientific reasoning. They might do but they also might not. The onus upon the scientific realist is to demonstrate that they must do. Realists have not done this. They have merely asserted it. In this thesis, my argument is that if we treat the non-human part of the world in experimental physics as the machine-half of the human-machine relations of modern technology then experimental physics can be made intelligible as a mathematically inscripted, technologically driven, metaphysics that does not necessarily need to have anything to do with Nature at all. My point is that, even if physicists need to be realists, then we can still, as outsiders, make experimental physics intelligible without committing ourselves to scientific realism. Bhaskar, by assuming the epistemological validity of experimental science, and, as a consequence, accepting the ontology revealed by experimental practices, has conflated epistemology and ontology himself and committed the very "epistemic fallacy" that he accuses the empiricist of making.

Both empiricists and realists neglect the productive role of knowledge in experimental physics and yet their arguments for the success of physics are premised upon its technological success. Knowledge does not necessarily follow existence, as Bhaskar claimed (1975, p.39), but, rather, as *techne*, promises the knowledge of how to bring things into existence. In chapters two and three I shall argue, following Heidegger, that laying down the law of the ground-plan of Nature was prior to the development of

[28] The anthropologist Tim Ingold introduced this term at a conference in Oxford on Biocentrism vs. Anthropocentrism in 1995. Ingold coined this term to capture the way that certain humans, namely "deep ecologists", have circumscribed this region of the world as "nature" and criticise any position that does not respect that region for being "anthropocentric". It is an apt word to describe Bhaskar's position.

seventeenth century mechanics and nineteenth century electromagnetism. I shall argue that the existence of a law is a premise for laying down the form of that law as something to work towards discovering. The content of that form was filled by the use of the geometrical abstracts of six simple machines: the wheel, the balance, the inclined plane, the wedge, the lever, and the screw. The discovery of that law was then a matter of discovering the techne of how to construct a machine as a demonstration and disclosure of that law. As I shall argue in chapters three and five this does not imply that the *techne* discovered existed prior to the process of constructing those machines.

Constant Conjunctions and Nature:

The process of experimentation is to disclose the natural mechanisms in operation during the construction of a repeatable process. This process needs to be isolated from interfering mechanisms if the desired disclosure is to be beyond criticisms. Experiments occur in closed systems. Both the CERN and Lancaster physicists have spent considerable efforts in attempting to shield their experiments from unwanted interference from outside elements. Bhaskar argued (1975, p.33) that constant conjunctions of events (if event A then event B) outside the artificial and closed systems of the laboratory are rare. Astronomy is a special case. However, even the predictive successes of astronomy have proved to be limited. Thunder and lightning are an example of a natural constant conjunction of events. Physics has been notoriously unsuccessful at accurately modelling these phenomena. The primary context of success in physics is largely restricted to the production of mathematical laws and causal explanations regarding the production of the constant conjunction of events in the performance of certain kinds of machines. Bhaskar argued that experimental physicists seek to isolate mechanisms and do not stop at noting the existence of constant conjunctions. I agree with Bhaskar on this point but I do not accept that it immediately follows that physicists must discover natural mechanisms. Mechanistic accounts were central to the task of building these machines in the first instance; they are also required for the physicists to have a complete account of the consequences of their own interventions. Without such an account, physicists can only hope to disentangle those consequences from the subtleties of Nature. The challenge for the physicist is to acquire the *techne* of the hows and whys of building, operating, and interpreting the experimental apparatus in order to acquire the episteme of natural laws. How do physicists attempt to rise to this challenge?, and, have they succeeded?

Bhaskar (1975, p.73) defined an open system as a system in which constant conjunctions do not occur. He stated (1975, p.134) that "[t]he judgement that the system is closed can only be made ex post *after* we have observed (and theoretically assessed) the observable situation." In other words, the determination of whether a system is open or closed is one that can only be made in hindsight in the light of our estimations of whether we have observed constant conjunctions (or not) and related it to our mechanistic models of the natural phenomena at our disposal. I agree with Bhaskar (1975, p.69) that "[r]egularity determinism is a mistake, which has been disastrous for our understanding of science." He defined regularity determinism to be the view that holds that constant conjunctions, of the form "when X then Y", are the limit of certainty for scientific investigation. Causal accounts are essential when developing machines. The identification of constant conjunctions is necessary but insufficient for an adequate understanding of how any machine works. However, regularity determinism is an essential part of the process of developing causal accounts of machine behaviour. One must be able to state that "whenever X then Y" as a starting point in the description and design of machine performances. But this is insufficient. One must also state the mechanism(s) that occur between X and Y before one can claim to have an understanding of how machines work. A complete understanding of such causal mechanisms is characteristic of *techne*. The understanding of classical mechanics takes this form. Bhaskar also argued that:

(1) even if the world is treated as if it is a complex of machines then we still can not reduce this complex to the principles of classical mechanics;

(2) the principles of classical mechanics cannot be themselves understood in terms of constant conjunctions;

(3) even if the world was a single machine then constant conjunctions would not provide an explanation of the world.

I agree with Bhaskar on these points. It is my view that the reason why the scientific understanding of the world should not be reduced to an interconnected complex of classical mechanisms is because the world is not comprised of such a complex. This complex, the machines used by experimental physicists, are only a part of the world. Furthermore, there is more than one kind of machine and its associated set of mechanisms. In terms of the experimental sciences, such as physics, chemistry, biochemistry, and genetics, etc., there are several distinct kinds of machines in operation, such as electromagnetic machines, quantum mechanical machines, bioassay machines, etc., with their own distinct technological objects, techniques, and operational practices. These machine-kinds can be interconnected but they cannot be reduced to one another. They are not the simple machines of classical mechanics. As I shall argue below, the ontological stratification of the experimental sciences is delimited by the distinction between these machine-kinds. For example, physics is itself comprised of historical strata of distinct machine-kinds. These are the mechanical, thermodynamic, optical, electromagnetic, quantum machine-families. None of these are reducible to the others. Most machines are hybrids of other machines and are transcontextural, when they share technological objects, because techniques and general models link them. However, though I agree with Bhaskar that limiting an account of the experimental sciences to the identification of constant conjunctions is a mistake, he missed a crucial point about the relation between such sciences and the machines that they use. The physical boundaries of these sciences are identical with the physical limits of the machines that these sciences use and their dissemination into the wider world. These sciences can only extend their ontology by innovating new machines. They overlap in so far as they use each other's machines. The objects of scientific thought, in these experimental sciences, are technological objects. I agree with Bhaskar that regularity determinism is disasterous for our understanding of the sciences but, in my view, mechanical realism may well prove disasterous for our understanding of Nature.

Bhaskar's Transcendental Argument for Scientific Realism:

Bhaskar claimed that a scientific realist interpretation of experimental science is necessary because only a scientific realist interpretation can make experimental science intelligible as an activity. Bhaskar's argument is based on the following premises:

(i)Scientific experimentation exists;

(ii)Experiments are physical and not just mental;

(iii)Experiments involve causal interactions with the material world;

(iv)Causal interaction is only possible because we are embodied beings;

(v)As embodied beings, we are subject to the same laws that govern the material world;

He presupposed that there are laws that govern the material world. His conclusion was that the same laws that govern the material world govern experiments. That conclusion presupposed conceptions of what human beings are, and what the world is comprised of. It is a statement of a realist interpretation of science and not an argument for one. It is an expression of the spirit of the enterprise.

Bhaskar described his argument as a transcendental argument because it is based on the question "what must be true in order for 'x' to be possible?" where 'x' is taken to be some self-evident fact about existence. Such arguments are based on premises of what is evident (or actual) and conclude that there is a 'more fundamental something' that is a condition for the possibility of these evidences (or actualities). Such arguments move from the phenomenal to the identification of enduring structures. Bhaskar started from the premise that experimentation occurs in science and asked what must the world be like in order for this practice to be intelligible. His question was: what makes scientific experiments possible? The function of a transcendental argument is to account for the possibility of some phenomenon. However, as Bhaskar pointed out, there may well be alternative transcendental arguments that explain the same thing differently and possibly better.[29] One transcendental argument may be better but there are no reasons to believe that any transcendental argument is a final one that is unsusceptible to revision and improvement. Bhaskar offered us an alternative as an example. His alternative transcendental realist argument for a realist interpretation of science ran along the lines:

(1) science exists;

(2) science discovers underlying mechanisms;

(3) if there were no underlying mechanisms then science would not be possible;

therefore there are underlying mechanisms. Even if we accept premises (1) and (2) it does not follow that

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[29] Kant was aware of the difficulties inherent in applying transcendental arguments to the experimental sciences. Kant too appreciated the difficulties in applying transcendental principles to the particularity of experiments in physics (and chemistry). The questions "How is physics possible?" and "How is the transition to physics possible?" were both central to his later work. These efforts were unpublished during his lifetime but have recently become available. Cf. Notes 22:282 to 22:452 in Kant, I., *Opus postumum*, Forster (ed.) Rosen & Forster (trans.), Cambridge University Press, 1995, pp.100-199.

the "underlying mechanisms" discovered by science are *in fact* "natural mechanisms". Bhaskar's argument presupposed the metaphysics of mechanical realism from the onset and, yet, it is a metaphysics that he does not address. Bhaskar's argument is based on a presumption of *mechanical realism* and, in my terms, is not a metaphysical argument at all. It is a statement of allegiance. His assumption of the necessity of a realist interpretation of experimentation for the intelligibility of science is based upon an appeal to the indubitability of the "internal rationale" of experimental physicists. By taking the "internal rationale" of experimental science as the only intelligible rationale, Bhaskar has conflated intentionality with actuality. This is a fatal move for a realist argument. It must be a criterion for any realist position that, in any practice, the intentions of the practitioners could be at odds with the actuality of those practices. It must be possible for someone to think that they are doing one thing when, in truth, they are doing something else. Otherwise no one could ever be fallible. Furthermore, given a plurality of available interpretations of any set of practices, there is a sufficient degree of ambiguity for those practices to be taken as successful by the practitioners. It is possible that experimental scientists could intend to reveal natural mechanisms but only produce artificial mechanisms; they would be internally successful and externally deluded. It is only necessary, for the continuance of the practice of experimental science to be internally intelligible, that the practitioners interpret the artificial mechanisms that they produce to be natural mechanisms. We only need to show the process by which this interpretation is made and it is externally intelligible as well. We do not need to accept that the "internal rationale" is justified by the continuance of the practices. For example, religions have been practised for thousands of years. Is it the only intelligible explanation of the existence and continuance of any particularly long lived religion that it must be based upon truth? If we were to adopt Bhaskar's style of argumentation then we would have to accept that it was. After all, the devotee, no doubt, would claim that their material practices were based upon the truth of their beliefs regarding the significance of those practices. Rituals for the dead would be a good example of material practices combined with beliefs about the worldly (as well as otherworldly) significance of these practices. Many religious beliefs are embodied in theories that appeal to some kind of intransitive cosmic order. However, non-believers would readily claim that those practices were based upon culturally sedimented beliefs, authorities, social power structures, and traditions, etc. We could argue that religion has maintained its existence through the maintenance of certain social structures, powers, and beliefs, and find it intelligible despite the "false consciousness" we have ascribed to its practitioners. We could equally argue this way about the conditions for the existence of experimental physics and make it intelligible. It depends upon the maintenance of certain social structures, powers, and beliefs. We do not need to accept the authority of either set of social structures, powers, and beliefs, to make either religion or physics intelligible. A similar argument could be made against Hacking's (1983) famous confession to be a realist about electrons because physicists claimed to spray them on mobidium spheres in their search for free quarks. It seems to me that Hacking should also be a realist about spirits because witch doctors claim to use them to heal the sick. After all, forms of shamanism have existed for much longer than experimental physics and, by both Bhaskar and Hacking's standards, the endurance of practice is a criterion for its truth. One can imagine an analogous argument for a realist theory of shamanism:

(i) shamanism exists;

(ii) it aims to achieve knowledge of, and access to, a spirit world for purposes of healing the sick, exorcising evil spirits, etc.;

(iii) it would not be intelligible as an existent set of practices, if it persists and does not actually achieve what its practitioners claimed that it did;

therefore, given (i) to (iii) above, shamanism must necessarily achieve knowledge of, and access to, the spirit world, and the spirit world exists. However, this argument, like Bhaskar's "transcendental argument", is a petitio principii because it presumes its conclusion: that the practitioners actually achieve what they intend to achieve.

Bhaskar presented a third form of transcendental argument:

(1) science exists;

(2) science is only intelligible if real causal mechanisms exist independently of science;

(3) science is intelligible; and, therefore: real causal mechanisms exist independently of science.

There are three main problems with this argument:

(1) It is circular. It begs the question;

(2) Bhaskar's argument rests upon the meaning of "intelligibility" but he does not define, qualify, nor discuss it;

(3) even if real causal mechanisms exist, we still need additional work to determine whether they are natural or not. It does not follow from the fact that a generative mechanism exists that it is a natural mechanism. It requires a presumption of mechanical realism to make this leap.

My argument in chapters five and six is that it is equally intelligible that such mechanisms are created by experimentation. My argument is that this process is analysable as a non-linear technological process. Any independence of the mechanisms discovered by experimentation is a consequence of the fact that it, as a process, is not completely under human control either. Nor would such a process be possible without human participation and partial control. This does not support scientific realism and yet makes experimental physics as a "policy realism" intelligible. However, given the power of the technological objects produced by experimental physics (i.e. nuclear power, radio communications, and lasers) the lack of control is something of considerable concern from a humanist and naturalist point of view. I shall return to this point in chapter six.

Bhaskar (1975, p.21) claimed that any adequate philosophy of science must grapple with "the central paradox of science". This "paradox" is that science is a social product that is concerned with a "knowledge of things that are not produced by men at all". It is my intention to cut through the Gordian knot of this "paradox". My argument is straightforward. Production is not purely a human activity. Human beings, on our own, have no productive capacities whatsoever. We must engage in disciplined practices with tools, machines, materials, <u>and other people</u>, in order to have any productive capacities at all. In order to become productively empowered human beings we must relinquish any possibility of absolute control. A carpenter does not have absolute control of the processes by which s/he makes a chair. S/he must learn how to make a chair and her/his body must be disciplined to be able to perform the technological practices required of it by her/his instructor. This is technological enframent and the motility of her/his body is inscribed and directed in the mimicry process of learning how to make a chair. Nor is there a singular process by which chairs can be made. The challenge for experimentation is to explore the productive possibilities of innovation. In chapters four and five I shall discuss the complex craft of experimental physics in detail but my basic argument is straightforward. In order to be able to build, use, and interpret, experimental apparatus and measuring instruments, a human agent needs to be trained in the technological practices involved. This training involves relinquishing absolute control over his/her body whilst transforming that body into a technological agent. The centre of control is the centre of the technological enframent and not the human agent as the human subject is both empowered and decentred by technique. It is this divergence of a centre from the human agent, and the dependence of technological enframent upon human participation, which presents "the paradox" that the objects of production are a social product and yet not completely controlled by human beings. There is, in fact, no paradox at all if we do not assume that the technological simply means "man made". Technological objects are made by the art. Experimental sciences are artificial processes and, therefore, any adequate philosophy of experimental science must grapple with the question: what is the artificial? Bhaskar has presumed that the answer to this question is simply "man made" and, consequently, he is confronted by a paradox which he can only resolve by assuming mechanical realism or considering experimental physics to be impossible.

However, it is not my intention to criticise Bhaskar, or any other scientific realist, for their position. They are as entitled to their opinion as anyone else is. I shall only criticise them for their uncritical acceptance of the metaphysics that their position presupposes. I agree that the spirit of the scientific enterprise, scientific progress, and scientific intention, is to achieve objectivity and rationality in scientific endeavours, and is also essentially a realist endeavour. However, I am of the opinion that we are fallible and we can misunderstand what we are doing and what is true. Scientific realism may well be mistaken and false; it might even be rewarded with the truth. That is not the question. Is it the only intelligible explanation of predictive success of physics, and the innovation of new machines in experimentation, that it is a natural science? My answer is no. It is not my intention to discredit or debunk experimental physics; I am trying to understand how it is possible. To this aim, the positivistic claim that science should be free from metaphysical speculation should be rejected because all truly novel theories require metaphysical interpretations.[30] I aim to unmask the metaphysical precepts that are implicit in the history and trajectory of the theoretical and experimental practices of working scientists because there is frequently a gap between the practitioner's perception of their own practices and the practices themselves.[31] Heidegger also dismissed

[30] For examples of these from contemporary experimental quantum physics see Cohen (ed.) (1997).

[31] Gooding was also aware of this "gap" (1990: p. 113, pp. 254-5) and noted the difficulties in attempts to reconstruct the original experiments from the physicists' own accounts. Latour, Collins, and Knorr-Cetina have also emphasised this.

the positivistic demand that all metaphysics is purged from science. New experiences require new concepts and, if we are to understand those experiences, we need to understand the metaphysics that made those experiences possible. In the next chapter I shall discuss the origins of this metaphysics.

CHAPTER TWO

THE MATHEMATICAL PROJECTION OF THE SIX SIMPLE MACHINES

"Philosophy is written in this grand book, the universe, which stands continually open to our gaze. But the book cannot be understood unless one first learns to comprehend the language and read the letters in which it is composed. It is written in the language of mathematics, and its characters are triangles, circles, and other geometrical figures without which it is humanly impossible to understand a single world of it; without these, one wanders about in a dark labyrinth."
(Galileo Galilei, *The Assayer*, pp. 237-8.)

"There remains one hope of salvation, one way to good health: that the entire work of the mind be started over again; and from the very start the mind should not be left to itself, but be constantly controlled; and the business done (if I may put it this way) by machines." (Francis Bacon, *The New Organon*, p.28)

"...not to know what it is but to know out of what it arises is most precious."
(Aristotle, EE, 1.5.1216b2)

A great deal has been written on the change in the conception of Nature that occurred during the "scientific revolution" of the sixteenth and seventeenth centuries. In the "traditional view" of the "scientific revolution" the rise of modern technology is taken to be derivative from the mathematical sciences; modern technology is taken to be "applied science". [1] However, the proponents of this view have not provided us with a satisfactory account of how this "application" occurred. Alfred North Whitehead (1925, p.32) considered the way that highly abstract mathematically formulated theories have been "effectively applied to practical affairs" to be the "paradox" of modern science. How did the mathematical natural sciences lead to modern technology? How were mathematical practices and technological practices connected? How was this connection possible? How was it justified? Ernst Nagel (1961) argued that the relations between modern science and modern technology are not as obvious and clear as the "traditional philosophy of science" has assumed. He maintained the view that modern technology is applied science but was aware that the character of "application" is an ambiguous one. J.K. Feibleman (1982) criticised philosophy in general, and the philosophy of science in particular, for its "traditional" neglect of technology.

In contemporary science studies considerable attention has been paid to technology to the extent that an "alternative tradition" has become fashionable. On this view, the experimental "natural"

[1] Whitehead (1925), Disjksterhuis (1961), Strong (1966), Westfall (1983), Koyré (1992), and Wolpert (1992), for example, all considered this derivative relationship between modern science and technology to be self-evident.

sciences, such as physics, chemistry, and genetics, are forms of "applied technology".[2] However, the characterisation of physics as "applied technology" only reverses the problem of how the "application" occurred. How was technology "applied" in such a way as to become the "natural science" of physics? How was this "application" justified? How was it conceptually possible? In order to understand experimental physics as "applied technology" we need to address how mathematics, machines, and natural phenomena were related. What understanding of technology do we need in order to understand the technological basis of the experimental natural sciences? What was the nature of the "application"? It is my view that we need to analyse physics at a "deeper" level than merely pointing out that the use of mathematics and technologies has been central to the experimental natural sciences since their origin in the sixteenth century. What presuppositions about both natural phenomena and technology permitted the use of technologies to understand natural phenomena? This is a question of the metaphysics that underlies the whole legitimacy of the technological disclosure of natural mechanisms. We need to understand how the reification of mathematics, as something objectively, eternally, and universally true, in the context of the Renaissance developments of the Medieval science of mechanics, allowed experimental physics to be *metaphysically operational* as a technological mode of disclosure. My argument in this chapter is that the precepts of mechanical realism provided the operational metaphysics of experimental physics.[3] Thus the mathematical description of the motions of the six simple machines (the wedge, the lever, the balance, the inclined plane, the screw, and the wheel) could be taken to be descriptions of the fundamental natural motions. This provided the sixteenth and seventeenth centuries with both a methodological and an ontological foundation for the mechanical and experimental natural philosophies of Galileo, Descartes, Bacon, Gassendi, Newton, Boyle, Hobbes *et al.*

Experimental physics emerged as a continuation of the ancient and medieval mathematical treatments of mechanics. It was situated, from its onset, within a cultural desire for organised technological powers combined with a reification of Euclidean geometry. Some contemporary historians of the science of mechanics also have this understanding.[4] The possibility of experimental

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[2] Jonas (1974), Kuhn (1977), Feibleman (1982), Heelan (1983), Ihde (1991, 1983), Mitcham (1994). Many contemporary historians of science and technology also share the view that technology preceded the sixteenth century "scientific revolution" and that, to a lesser or greater degree, physics is "applied technology". For examples see Hill (1984); White (1962, 1984); Landels (1978); Hodges (1974); Dugas (1955); Forbes (1955); Chatly (1942); Rostovtzeveff (1941); Brett (1939).

[3] As I stated in the last chapter, an operational metaphysics is distinct from an interpretive metaphysics. The latter is required to interpret disclosures whereas the former is required for the existence of disclosures in the first place.

[4] Long (1997) argued that there were close ties between the patronage of political elites and sixteenth century mechanics. This point was also made by White (1962 pp.21-9). Kaufman (1993) argued that art, science, technology, and humanism were inter-related across disciplines in the circles of the Imperial court of Rudolf II (c.1577) in Vienna of the sixteenth century. Bennet (1986) argued that

physics did not primarily occur because of the success of Copernicus and Kepler's mathematical treatments of planetary motions. There is not any possibility of experimenting upon planetary motions (at least not yet). Experimental physics emerged due to the successful mathematical treatment of mechanical devices within societies that valued the economic, political, and military advantages of technological innovations. Appeals to the successes of mathematical astronomers were *rhetorically* connected to the successes of mechanists, as part of the movement towards a unitary conception of natural science. This occurred within the cultural context of patrons; mechanists were providers of technological innovations for economic, political, and military goals. The precepts of the mechanical realist metaphysics were required (at least implicitly) to conceptually connect, via the mathematical science of mechanics, the astronomical phenomenon of planetary motion with terrestrial mechanical devices, and present both as aspects of a unitary natural science. The mechanical science of Galileo was the culmination of Medieval and Renaissance developments of geometrical mechanics and technological innovations; it was not the radical break from his predecessors that it has been presupposed to be. However, his physics presumed and attempted to justify the precepts of mechanical realism, and it was this presumption and attempt that was novel, heralded the "mechanical world view" of seventeenth century mechanical and experimental philosophies, and was a pre-requisite for conceptions of modern scientific technology and modern experimental physics. In order to understand the metaphysical origin of experimental physics we need to historically trace back its enduring essence through its current manifestation as a modern technoscience.

Modern Technology: The Technical Imperative:

In this section I shall introduce Martin Heidegger's and Jacque Ellul's characterisations of the essence of modern technology and its relation to modern mathematical science. Although both Heidegger and Ellul offered us clear and insightful analyses of modern technology neither was particularly clear on the relationship between mathematical physics and modern technology. In order to understand their characterisations we need to examine their distinction between premodern and modern technologies. My starting point is Marx's definition that premodern technologies were based on local needs and *craft practices* whereas modern technology is based on the *industrial and mechanised organisation of labour based on capital and science* (1967). I take this definition to be clearly influential upon many contemporary analysts of modern technology. Many twentieth century writers, following Marx, have taken the nineteenth century "industrial revolution" to be the historical period in which a radical

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practical mathematics grew in England during the sixteenth and seventeenth centuries through the work of Dee, Hood, Davis, Recorde, Diggs, the Gresham College, Norman, Gilbert, Gellibrand, Briggs, *et. al.*, in developing techniques to attempt to solve problems of national import. See Johnson (1940) for a discussion of the close ties between Gresham College, the English navy, and the development of English mathematics in the early seventeenth century. Also see Bedini (1994), McMullin (1967), Scholfield (1970), and Rossi (1970).

transformation between premodern and modern technology occurred.[5] They distinguished between premodern and modern technology broadly on the basis that premodern technology was local, pluralistic, unscientific, and largely based on craft technologies, whereas modern technology is global, unitary, based on mass production, and is scientific. For these writers, premodern crafts were based on *disorganised processes, pluralistic techniques, and skills* whereas modern technology is based on the *theoretical organisation of technology into science as a unitary phenomenon*. This distinction is clear but it raises several questions. How was this transformation from premodern to modern technology possible? Why did it occur during the nineteenth century? What relation did it have with modern science? My position is that this transformation occurred earlier than the nineteenth century and, in fact, made both the "scientific revolution" and "the industrial revolution" conceptually possible. The transformation from premodern arts and crafts to modern technology arose primarily from a transformation in the conception of the origin of technological powers that occurred *at the same time* as the mechanical-world view of the mathematical natural philosophies. It was this conceptual transformation that made both experimental physics and modern technology conceptually possible. Mechanical realism underpinned the sixteenth and seventeenth centuries' conception of technological powers and natural phenomena as having *the same unitary origin and manifest according to the same principles or laws*. The possibility of modern technology occurred *simultaneously* with the possibility of modern experimental sciences because of the emergence of this conceptual synthesis of the origins of both natural phenomena and technological powers. Once this metaphysical conceptual synthesis had been made then the conception of modern technology as a *unitary phenomenon*, manifest according to universal natural laws, was possible. Technology could then be invented as a process of unlocking and utilising natural forces, causes, and powers. It could be treated as a unitary kind of relationship between "Man" and "Nature" in which "Nature" could provide the means for its own domination by "Man". Technology could then taken to be a neutral process that was accessible to "universal rationality", defined in terms of "technical rationality" on the basis of a concept of "efficiency"; Nature was conceptualised in terms of universal mathematical laws, materials, mechanisms, "necessity", and "efficient causes".

Mechanical realism emerged within the contexts of the sixteenth and seventeenth centuries' expansion of technological powers (literally around the globe) and the continuation of pre-sixteenth century attempts to mathematically describe the six simple machines in terms of fundamental mechanical principles. The precepts of mechanical realism emerged from the mathematical science of mechanics. The novelty of the sixteenth and seventeenth centuries' mathematical science of mechanics was the emergence of an important *symmetry*: both natural phenomena and technological powers were taken to be explicable and manipulable according to the same kind of principles or laws. This was simultaneously a naturalisation of mechanisms and a mechanisation of Nature. It was this naturalisation

[5] For example, Cohen (1955), Mumford (1963), Ellul (1964), Marcuse (1966), Horkheimer (1974), Heidegger (1977), Habermas (1987), Adorno (1994), Mitcham (1994), and Steigler (1994).

of mechanisms that was the crucial novelty. This was situated within the Archimedean-Aristotelian framework but was a metaphysical *synthesis* of natural philosophy and mathematical mechanics that conceptually allowed a reduction of Nature to the mechanical: that which permitted description in terms of mathematical mechanics. It was the subsequent *interpretive metaphysics* of the seventeenth century, such as the Newtonian mechanical system of the world, Gassendi's atomism, or Descartes' metaphysics, that constituted the epistemological rupture by introducing interpretations that would have been nonsensical to previous natural philosophers. However, those interpretive metaphysics presumed the validity of the transformation of the Medieval and Renaissance mathematical treatments of mechanics from a means of disclosing the mathematical principles of simple machines (and all other mechanical devices by derivation) to a means of obtaining knowledge of the mechanical laws of Nature. This premise allowed technological innovation (bringing novel technological powers into the world) to be taken as nothing more than taking advantage of those laws. Thus technological innovation (the expansion of technological powers) could be treated as human participation in the natural order of things disclosed by the mathematical mechanical sciences. In the sixteenth and seventeenth centuries the confidence in the human ability to construct and use machines to produce new technological powers grew to such proportions that machines were reified. The presupposition of mechanical realism allowed these reified machines to become transparent means of disclosure at the service of "Man". Machines could be used to disclose the mechanical principles of the Grand Machine, the Universe and everything contained therein, and conceived as a self-evidently rational exploration of Nature. The scientific realist notion of progress was henceforth implicitly premised upon appeals to technological innovation and power.

Heidegger presented a phenomenological analysis and Ellul presented a socio-political analysis of modern technology and the mathematical sciences. Both of these thinkers were influential upon subsequent thinkers, their insightful analyses complement each other, and they raised crucial questions for any intelligible analysis of modern technology and science.[6] Both Ellul and Heidegger approached technology from a post-Hegelian perspective of dialectically interpreting experience in the light of an interpretation of history and, consequently, have many points of similarity with Marx and Lukacs.[7] They were also both concerned with the question of how we can attain a free relation with technology. In order to elucidate both of these writers characterisations of technology, I shall compare

[6] Heidegger was clearly influential (as well as Marx) upon Arendt, Horkheimer, Habermas, and (at least indirectly via Habermas) Marcuse. Both Ellul and Heidegger were central starting-points for Steigler (1994) and many "postmodern" analyses of technology. See Winner (1977) for a discussion of the influence of the above thinkers (as well as Marx) upon the notions of "autonomous technology" and "efficiency". See Mitcham (1994) for a discussion of the influence of both Heidegger and Ellul on "the humanist tradition". To my knowledge neither Heidegger nor Ellul discussed, or made reference to each other's work, despite the fact that they were contemporaries.

[7] Although Lukacs (1976, p.xxiv) criticised Heidegger for his sublimation of a critique of society into a purely philosophical problem.

Ellul's *The Technological Society* (1964) with Heidegger's *The Question Concerning Technology* (1977a).

Ellul's questioned the meaning of the dominance of technique for the human present and future. Heidegger was concerned with preparing a way in which we could question the essence of technology and develop a free relationship with it. *The Technological Society* is a narration of the tragedy of a civilization increasingly dominated by technique. *The Question Concerning Technology* was an attempt to unconceal the essence of technology and relate it to truth. Ellul placed an emphasis upon the erosion of moral values brought about by technicism, an examination of the role of technique in modern society, and a historical disclosure of the forces that have shaped the development of technical civilization. Heidegger examined how the instrumentalist and anthropological definitions of modern technology, whilst being correct, have made us blind to the essence of technology. The anthropological definition is that technology is a human activity and the instrumentalist definition is that technology is a means to an end. For Heidegger, the essence of technology was not to be considered as something technological and he considered the claim that technology is "something neutral" to be the worst misconception of technology possible because it immediately delivers us over to an unthinking relation with it. Heidegger agreed (1977a, pp.3-6) that technology is a human activity in the sense of positing ends and procuring the means to them. He accepted that it is also an instrument in the sense that the manufacture and utilisation of equipment, tools, and machines, as well as the needs and ends that they satisfy, all belong to what it is. However, his starting point was that, if we are to understand the essence of technology, we need to ask: "what is the instrument itself? Within what do means and ends belong?"

For Heidegger, modern technology was a mode of disclosure in which beings are set in place, ordered, in such a way as to "put to nature the unreasonable demand that it supply energy that can be extracted or stored as such."(1977a, p.14) Heidegger termed this mode of disclosure as *Herausforden* (challenging).[8] To use Heidegger's examples, modern technology challenges a tract of land to yield coal and ore. The earth is disclosed as a coal-mining district and the soil as a mineral deposit. Air is set upon to yield nitrogen for the mechanised agricultural industry and the earth is set upon to yield uranium for the atomic weapons and power industries.[9] Modern technology sets upon and challenges Nature to disclose itself, unlock and expose itself, as energy or resources for future use. It is

"always itself directed from the beginning toward furthering something else, i.e. toward driving on to the maximum yield at the minimum expense. The coal that has been hauled out in some mining district

[8] Lovitt noted (Heidegger, 1977a, p.14 fn. 13) that the verb *herausforden* could be translated as: to challenge, to call forth, to summon to action, to demand positively, or to provoke. A literal translation would be "to demand out hither".

[9] Lovitt noted (Heidegger, 1977a, p.15 fn 14) that the verb *stellen* (to place or to set) has a variety of uses. It can be translated: to put in place, to order, to arrange, to furnish, or to supply. It can also be translated, in a military context, to challenge or to engage.

has not been supplied in order that it may simply be present somewhere or other. It is stockpiled; that is on call, ready to deliver the sun's warmth that is stored in it. The sun's warmth is challenged forth as heat, which in turn is ordered to deliver steam whose pressure turns the wheels that keep a factory running." (1977a, p.15)

It is this availability for use in the future (without any consideration of the particularity of that future use) that Heidegger termed *Bestand* (standing-reserve).[10] He used this term to characterise the way in which everything is commanded into place and ordered according to the challenging essence of modern technology as it comes into presence as a mode of disclosure. Objects lose their character as objects when they are disclosed as standing-reserve. It was for this reason that Heidegger considered the instrumental definition as something that was both correct and concealed the truth. Modern technology can only disclose Nature as standing-reserve because it challenges human beings to exploit Nature in this way. This challenging is an imperative in which the participation of human beings in the ordering disclosure is essential if it is to happen at all. However, what is disclosed by this ordering is not controlled by human beings. By responding to the challenging, human beings are ordered into modes of disclosure and it is the way of disclosure that discloses objects as the objectlessness of standing-reserve. Thus, for Heidegger, the anthropological definition is correct and conceals the essence of modern technology. Technology sets-upon, challenges, and gathers human beings together "to order the real as standing-reserve in accordance with the way that it shows itself" as a mode of disclosure. (1977a, p.19) Heidegger termed this as *Ge-stell* (Enframing). This imperative is not something technological (in the same way that pistons, rods, and chassis are technological) and the assembling of the technological, the ordering of the stockpile of components falls within technological activity. Technological activity is merely a response to the imperative, the challenging of *Ge-stell*, and it neither comprises *Ge-stell* nor brings it about.

Like Heidegger, Ellul considered technique to have its own reality, substance, and particular mode of being. Modern technology, or the technical phenomenon, was ontologically identical with the technical society. He characterised the technical phenomenon as a perpetual state of social inequilibrium and defined "technique" as "the totality of methods rationally arrived at and having absolute efficiency (for a given stage of development) in every field of human activity" and proposed that it should be studied as a sociological phenomenon.[11] He used the term "technique" to refer to any complex of standardised means for attaining a predetermined result. This term was used to refer to any deliberate, stable, and rationalised productive behaviour. He considered a means to be stable if it was repeated to realise stable intentions. Technique is the means and the ensemble of means employed to attain results. Technical operations include "every operation carried out in accordance with a certain

[10] Lovitt noted (p.17 fn. 16) that *Bestand* is ordinarily translated as "standing by" with its connotation of the verb *bestehen* ("to last" or "to undergo"). Lovitt also noted that *Bestand* contrasts with *Gegenstand* (object).

[11] Ellul, (1964) "Note to the Reader" p.xxxv

method to attain a particular end" in which the method employed characterises the operation. (1964, p.19) For Ellul, (1964, pp. 11-9, p.79) technique was objective in the sense that "it is transmitted like a physical thing" through the organisation of productive performances. Technique is the organised ensemble of *all* techniques that are used to secure any end whatsoever. It can *in principle* only provide technical and quantitative solutions to technical problems. Ellul did not intend to convey any metaphysical notion of "technological determinism" in his characterisation of technique because, for Ellul, things could always differ from the contingent actuality of the present. If technique is a "blind force" it is so because human beings have closed their eyes to the alternatives. Technique has the character of an imperative that only achieves its power because human beings respond to its demand. It is this conception of technique, in terms of a unitary imperative to order the world, which has a considerable parallel with Heidegger's conception of *Ge-stell.*

Ellul characterised the modern conception of "rationality" in terms of a "technical rationality" which brings mechanics to bear on all that is spontaneous. It operates through systematisation, division of labour, creation of standards, production of norms, and the reduction of method.[12] Any intelligible critical analysis of any productive technology, technical decision, or process, must be placed into a socio-economic context of political interests and organisation. Every technology is a social ordering and organisation of production processes directed to the satisfaction of socially (politically and economically) emergent goods (or ends). A technological order is a social order *and vice versa*; non-human artifacts are participants in the shape and direction of society. Technological choices affect the social and political landscape. Although "technical rationality" is socially, economically, and politically situated it is also situated within a technological background. It can then, in turn, reiteratively shape and limit the social, economic, and political landscapes. "Technical rationality" is a *bounded and evolving rationality.*[13] It is a context-dependent rationality that is related to technology through context-dependent information. Within any particular bounds, particular choices are "technically rational" and others are not. Context-dependence gives technology a dynamic and evolutionary agency. As Mueller put it

"... the form taken by a technological system is not a *design* but an *evolutionary trajectory.* The trajectory is defined as its operations adjust to the specific social, geographical, economic and political characteristics of its environment, and overcome the technical problems posed by its growth and its competition with other technologies. Anyone familiar with the history of a large-scale technological system knows that an attempt to implement the simplest idea can create vast numbers of unforeseen problems. It is the process of solving these problems – not of preconceived design – that gives technology its shape." (1987, p.32)

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[12] The notion of scientific rationality was heavily criticised by the so-called neo-Marxist-Frankfurt school, Horkheimer (1974), Adorno (1994), Marcuse (1966), and Habermas (1987).

[13] See Simon (1981) and Mueller (1987) for detailed discussions of this definition.

Thus "technical rationality" is situated within social, economic, and political contexts of problem solving. The horizon of possibilities and the ways to reach it are shaped by the social, political, and economic choices and problems, for which technology has been constructed to solve. It is no more neutral than the contexts in which it arises. The evolution of any technology is shaped by social, political, and economic trajectories because the uses to which any technology is put to are the content of that evolution. In turn, the "technically rational" also has shaped political, economic, and social possibilities.[14] Technical knowledge, as an active form of knowledge directed towards efficiency, has to be context-dependent, if it is to be able to provide the functionality required for "technical rationality". Bounded and evolving technological rationality, or context-dependent rationality, has a bounded and evolving concept of efficient functionality as its basis for informed choice. Efficient functionality is also context-dependent trajectory of human-technique relationships in a changing political, economic, social, and technological environment. By bringing new things into the world, such as hydrogen bombs, antibiotics, contraceptives, radio, motor cars, etc., technology transforms the world. New political, economic, and social possibilities arise because new modes of social organisation become possible. These possibilities, when realised, shape the directions of technology. Technological objects are non-linear complex objects that are emergent through interconnected socio-technical feedback relations and an evolving socio-technological background.

For Ellul, every intervention of technique is, in effect, a reduction of facts, forces, phenomena, means, and instruments to the schema of mechanistic logic. The human agent becomes transformed into an agent that is defined in terms of her/his performance and function, as an integrated and articulated component, in an ensemble of functioning agents. Technique sets upon and organises human agency. This conception of technology has a considerable parallel with Heidegger's conception of technology in terms of enframing and challenging. The project of "the technical man" is a perpetual search for the "one best way" to achieve any designated objective and the perpetually expanding and irreversible role of technique is extended to all domains of life. The choice of method/technique is made in reference to the satisfactory stabilisation of measurements, calculations, *and productive practices*, in relation to an intelligible causal account. Such a choice can not be divorced from the socio-technical backgrounds against which it is made and emergent from. It is a matter of paradigmatic socio-technical consensus. Once this choice has been made then the method/technique becomes a technological object available for future work. In Heidegger's terms, this method/technique is placed as available standing-reserve within the public realm. There it is placed in competition with other technological objects for ordering within the technical imperative towards "efficiency". The socio-technical winner is taken to be "the most efficient" and "the one best way". Until it is replaced by another technique, "the one best way" achieves a technical autonomy in practice because technical practitioners, also under the sway of the technical imperative, are obliged to use it. Its results are

[14] Wajcman (1991) made this point about domestic "labour saving" devices; Wallis & Baran (1990) made this point about television news broadcasting; Walsh (1980) made this point about contraception.

indisputable until a "better" technique takes its place. Once a technique has become established as "the one best way" then it is no longer an object for technical deliberation. The technical practitioner is committed, whilst under the sway of the technical imperative, to perform her/his operations in "the most efficient" manner which, of course, requires using "the one best way". It is this conception of technique that has a parallel with conception of *Ge-stell* as *Geschick* (destining).[15] Challenging sets human beings on a way of disclosure of the real as standing-reserve. It simultaneously sends and gathers human beings upon this way of disclosure. It is modern technology itself (as *Ge-stell*) which gathers together and sets-up human beings into this mode of ordering and disclosure. Like Ellul, Heidegger rejected the idea that this involves "a fate that compels... where 'fate' means the inevitableness of an unalterable course" (1977a, p.25). For both Heidegger and Ellul, Western Civilization is a progressively technical one committed to the quest for continually improved means to carelessly examined ends. Technique transforms ends into means (and vice versa). Human agents are compelled to adapt to a technical substratum of human existence that has become so overwhelmingly immense that we are unable to cope with it as a means and, consequently, treat it as an end. In Heidegger's terms, modern technology conceals itself and yet is everywhere. "Know-how" is treated as the ultimate virtue.[16] Heidegger based his distinction between *Ge-stell* and *techne* upon the change in the destining of disclosure. The ancient handicrafts were a different mode of disclosure. They participated in "bringing-forth" beings into the world (*poiesis*) as ends-in-themselves. They were intimately bound-up with *alethia* (truth) as a mode of disclosure and presencing of the real. This truth was bound up with modes of completion and perfection and did not correlate with the definition of truth as "correctness" (*veritas*).[17] What was once prized as a good in itself, for its own sake, is transformed into something that is only of instrumental value, for the achievement of something else. Under the sway of technique everything (including technique) is transformed into standing-reserve. *Technique* and *Ge-stell* capture the same essence of modern technology.

The dominance of technique upon state controlled capitalist economies in which planning becomes "the order of the day" for the economy as a whole. Technique imposes an impersonal centralism upon the economy. For Ellul, this impersonalised centralism does not result "from the machinations of evil statesmen" and it can not be controlled by public opinion (if we accept Ellul's claim that public opinion is primarily orientated towards performance and satisfaction of socio-technical ends.) "The conflict of propaganda takes the place of the debate of ideas", as R.K. Merton put

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[15] Heidegger (1977a, pp. 24-6.)

[16] Cf. Aristotle (N.E. Bk. 6) for his distinctions between the intellectual virtues of *episteme*, *techne*, *sophia*, *nous*, and *phronesis*. The criticism of the dominance of the intellectual virtue of *techne* in modern society was central to the critical analyses of modern society presented by Arendt (1958), Habermas (1987, 1983), and Dunne (1993).

[17] Heidegger (1977a, pp. 6-13). I shall discuss the significance of this mode of disclosure for an understanding of the relationship between the art of experimental physics and truth in chapters four and six.

it, when every part of a technical civilization responds to the socio-technical needs generated by technique itself, as if they were responding to immutable "laws of development", and "technology becomes more like the new god."[18]

For Ellul, the machine has created our world and without the machine the world of technique would not exist. However, the history of technique is not the history of the machine. Technology and the machine are not identical (1964, p.5). This point was also made by Heidegger (1977a, p.23). Technique does transform everything into machine processes but it has taken over all human activities and not just those that involve machines. Technique inventoried everything according to its utility and ordered everything in line with the machine. Thus it is technique itself which makes the machine possible. Machines did not integrate themselves into nineteenth century European society; technique integrated machines into society. Like Heidegger, Ellul warned us against considering the essence of technology as something technological. The "[a]ll embracing technique is in fact the consciousness of the mechanised world" and it is this "consciousness" which manifests itself as the imperative to integrate everything into the mechanised world and "will assimilate everything to the machine; the ideal for which technique strives is the mechanisation of everything it encounters." (1964, pp.6-12) Technique has become the substance of human agency and is integrated with it. Technique is distinct from the machine and has become autonomous within society. It leads to mechanisation, via the action of the machine, by applying the "know how" of mechanisation to domains which were previously "lacking" machines. Whereas "primitive" productive activities "spontaneously imitate nature" it is the processes of refining abstract requirements, which lead to criteria of selectivity that lead from "the imitation of nature" to "the ways of technique". (1964, p.20) The intervention of "technical judgements" provided an awareness of a plurality of novel means, methods, and tools. It allowed a "more extensive and less rigid experimentation" and "multiplie[d] technical operation to a high degree of diversity". Craft practices became possible through the intervention of "technical judgement". However, once "technical judgement" was directed towards "efficiency" its operation was transformed into "technical rationality". Instead of multiplying the technical operations available for "technical judgement" it performed the opposite. It reduced the multiplicity of means to "the most efficient one"

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[18] Merton's introduction to *The Technological Society*, pp.viii – xiii. Fournier D'Albe (1926) also made a similar point. He considered this "new god" to be the ancient Greek god of fire and making: Hephaestus. He made many of the points raised by Heidegger and Ellul but affirmed modern technology. It is quite ironic that, with hindsight, Fournier D'Albe's affirmations were situated in the context of the post "Great War" relief. He condemned the insanity of that war and affirmed the "golden age" of technology and science that he believed was on the horizon. He was unable to foresee that the insanity was about to reach unprecedented levels. Ellul and Heidegger's critiques of modern technology should be situated in the context of post WWII and Cold War reactions against the juggernaught and tragedy that modern technology had become. See also Winner (1977) for discussions of the autonomy of technology in the actuality of the World Wars, the Cold War, and Vietnam.

(1964, p.20-1).[19] The "technical phenomenon" is the drive to find this "most efficient" means. This is a technical imperative, which pervades all human activity, and "it ranges from the act of shaving to the act of organising the landing in Normandy, or to cremating thousands of deportees." (1964, p.21) Every material technique is subordinate to its immediate result and "efficiency" is determined by choosing the technique that produces the most satisfactory result. Satisfaction and its achievement is a social and psychophysical phenomenon and, hence, the mechanical realist characterisation of "efficiency" as the consequence of the "correct" application of "natural law" is supportive of inevitability and necessity of technique. For Ellul, the technical phenomenon is artificial. Technique is opposed to Nature. Art, artifice, and technique are attempts to create an artificial system. It is this attempt that Ellul termed as "the societal gamble": a gamble on the superiority of an artificial world over the natural world. The mechanical realist presupposes the facticity of the premise that only those acts of creation permitted by "natural law" are possible. Thus the creation of an artificial closed system can disclose "natural law". The means at our disposal may well be artificial means, as Ellul pointed out, but this, in itself, in my view, does not undermine the deterministic presuppositions of mechanical realism. The mechanical realist presupposes that only those artificial means that function according to "natural law" are capable of functioning at all. Human agents may well have only artificial means at our disposal but, for the mechanical realist, these means are only capable of being means in virtue of their utilisation of "natural mechanisms". For Ellul, the artificiality of the world created through technique implied that it is radically different from the natural world. However, for the mechanical realist, the only artificial worlds that are possible are the ones that are constructed in accordance with "natural law". Hence, once mechanical realism has been presupposed any artificial world is not radically different in kind from the natural world. It is merely a counterfactual. Both artificial and natural worlds are manifest according to the same "natural laws". The only difference between the two, on the mechanical realist account, is that the former requires human intervention to occur whereas the latter is the result of a lack of human intervention. For the mechanical realist, such as Bhaskar, this is a requirement for the intelligibility of experimentation. However, for Ellul, the artificial world destroys and replaces the natural world. It does not even allow the natural world to restore itself or enter into a symbolic relationship with it. Accordingly, these two worlds have nothing in common. Just as hydroelectric installations take waterfalls and lead them into conduits so the technical milieu absorbs the natural. Heidegger (1977a, p.16) also used the example of the hydroelectric plant to describe the way that the Rhine is disclosed as hydraulic pressure for an interlocking complex of turbines, electromagnets, power stations, and a network of cables, set-up to provide electricity as standing-reserve. The river is damned up into the power plant and is transformed into a water power supply. Even to the extent that it is still a river in the landscape, it only remains so as an object for the tourist industry. We are rapidly approaching a time when there will no longer be any natural environment at all.

How did Ellul and Heidegger relate science and technology? Ellul used the example of Archimedes to claim that mathematics and technique had been bound together as far back as ancient

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Greece. However, noted Ellul (1964, p.28), for Archimedes (as well as Plato), the goal of mathematics was contemplation and not application. Ellul posited distinctions between art, science, and technology. Art was concrete and subjective, science was abstract and objective, and technology was concrete and objective. Technique creates the reality it describes. Ellul was critical of the view that modern science is pure theory and modern technology is applied science. He was also critical of the view that technology figures at the point of contact between material reality and the scientific formula. He considered these views to be "radically false" because they are "only true of the nineteenth century physical sciences and [are] not true of science and technique in general." (1964, p.7) In Ellul's view, technique preceded science ("even primitive man was acquainted with certain techniques") but only began to develop and extend itself when science appeared. Technique required science to progress because it had to wait for science to provide the solutions to the problems posed by the repeated experiments of technique. How did science provide the solutions? What were the problems? Ellul did not address these questions. He merely maintained that the border between technological and scientific activities is not sharply defined and that technique provides preparatory work for scientific synthesis. Ellul provided the example of the steam engine to illustrate this point (1964, p.8). In his view, the steam engine was the product of technical trial and error sequences of invention and improvements and scientific explanations came much later. However, he did not provide us with an account of how those explanations were forthcoming. Nor did he show us how they were related to invention. How did precision and explanation solve the problems of technique? Ellul (1964, pp.8-9) did not explain this to any greater depth than arguing that there is an increasing interaction between scientific research and technical preparation to such an extent that science can not progress without the technical means to do so. According to Ellul, Faraday was unable to precisely formulate his theories about the constitution of matter because of a lack of high-vacuum techniques. Did Ellul mean to imply that somehow high-vacuum techniques were necessary for the precise formulation of Faraday's theories? Surely, if technique does not have anything at all to do with Nature then there would be not any necessity for any particular technique for the scientific synthesis to proceed. What was the "matter" that Faraday wished to explain? Ellul did not address these questions either. Of course the work of large scientific research is increasingly technical work and "pure science" is becoming increasingly "applied science". Science has become the instrument of technique because scientific discoveries are increasingly implemented in every day life before the consequences of that implementation have been considered. Modern scientific research increasingly requires large teams of researchers, enormous amounts of money, and the aid of machines. It requires technique as a necessary condition of its existence. Ellul argued (1964, pp.17-8) that science without technique is merely hypothesis and theory. But why? If technique and Nature are independent, as Ellul maintained, then why is technique necessary for natural science? For Ellul, mathematical techniques were central to his definition of science. In his view, only that which can be expressed numerically can be said to be scientific and, hence, the scientific use of technique is that of reducing the possibilities of investigation to the calculation of numbers. However, for Ellul, (1964, p.27) it is also the creation of general explanatory theories which makes science distinct from technique.

Ellul assumed that the sixteenth and seventeenth centuries were lacking in technique "in all areas but the mechanical" and the ideals of universality and humanism of that period resisted reducing the idea of human progress to that of technical progress (1964, pp.38-42). For Ellul, (1964, p.45) the seventeenth and eighteenth centuries' "scientific progress" prepared the way for nineteenth century's technical progress; scientific discoveries provided the necessary conditions but not the imperative. However, Ellul maintained that the natural philosophies of the eighteenth century were concrete, bound up with material results, naturalistic, and, sought to know and exploit Nature. But, for Ellul, these ideas were restricted to an intellectual elite and could not motivate the population of Europe to value the excellence of technical progress, and, consequently, the eighteenth century was only a preliminary phase of technical application. In my view, it was this historical interpretation that prevented Ellul from being able to identify how the origin of modern science was bound up with technique from its onset. For Ellul, modern science became bound up with technique during the nineteenth century's "industrial revolution" development of the machine and the application of technique to all spheres of life. The work of technique, the mechanisation of all human spheres of action, was a systematisation, unification, and clarification of everything (1964, pp.43-3). Ellul observed (1964, p.86) that science has been becoming increasingly governed by technique since the nineteenth century to such an extent that the smashing of the atom and the smashing of Hiroshima (and Nagasaki) are manifestations of the same imperative.[20] Technique is globalised through the educational and technical dissemination of European values, projects, techniques, and technicians. It is a global unification of a monolithic Western mode of social organisation and can not be anything other than totalitarian because the imperative towards "efficient" intrinsically requires the absorption of any plurality of function into a "scientific" unification in order to maximise "data", co-ordination, and exploitation (1964, p.125). This involves the total organisation of the human population to achieve "efficiency" and "maximise results" in every area of human endeavour. It is this totalitarianism that generates the monopoly of technical phenomenon and makes it an autonomous method of action that achieves its autonomy by being available as "the best technique". This is the meaning of use and, to the extent that use in experiment is underdetermined (otherwise there would be no experiment), it is the task of experimentation to stabilise technique. In this sense, it is the whole technical phenomenon, technological society, which is itself the experiment. This is why it is characteristic of a gamble. For Ellul, the technical phenomenon arose from the entire post eighteenth century technical Western Civilization. As a technical civilization, the West is entirely constructed in terms of technique to such an extent that only that which is technical is considered to be part of civilization. Everything in a technical civilization must serve a technical end and anything non-technical is either excluded as "inefficient", "subjective", or it is reduced to a technical form. Ellul accepted that this imperative somehow developed out of the science of mechanics

[20] Cf. Chaloupka (1992) and Easlea (1983) for discussions of the political and socio-technical trajectories implicit in the construction of the technosciences of atomic physics and nuclear power technologies.

but, for Ellul, its origin was "mysterious and enigmatic" (1964, p.5 and p.21). This acceptance reveals a considerable parallel with Heidegger.

For Heidegger, it was precisely the monolithic character of *Ge-stell* which "threatens to sweep man away into ordering as the supposed single way of revealing, and so thrust man into the danger of the surrender of his free essence" (1977a, p.32). Heidegger criticised the view "modern technology is something incomparably different from all earlier technologies because it is based on modern physics as an exact science" because modern physics "as experimental, is dependent upon technical apparatus and progress in the building of apparatus. The establishing of this mutual relationship between technology and physics is correct... ...The decisive question still remains: Of what essence is modern technology that it happens to think of putting exact science to use?" (1977a, p.14) For Heidegger, human beings are challenged by *Ge-stell* to disclose Nature as the standing-reserve of energy, and this attitude, on the part of human beings, was first displayed in the rise of modern physics as an exact science. Physics was a "way of representing [that] pursues and entraps nature as a calculable coherence of forces" and even as pure theory "sets nature up to exhibit itself as a coherence of forces calculable in advance, it therefore orders its experiments precisely for the purpose of asking whether and how nature reports itself when set up in this way." (1977a, p.21). Heidegger maintained his view that "mathematical physics arose almost two centuries before technology" but claimed that because "physical theory prepares the way first not simply for technology but for the essence of modern technology" then modern physics "is the herald of Enframing, a herald whose origin is still unknown." (1977a, pp.21-2) Heidegger argued (1977a, p.22-3) that, despite the fact that "chronologically speaking" modern physics began in the seventeenth century and machine-powered technology began in the latter part of the eighteenth century, the essence of modern technology was "the historically earlier". Modern physics, according to Heidegger, was itself challenged forth by the essence of modern technology. It was the technological imperative of *Ge-stell,* the demand that Nature is orderable as standing-reserve, that set-up physics as a means by which Nature was disclosed "in some way or other that is identifiable through calculation and that it remains orderable as a system of information." Thus for Heidegger, the essence of both modern physics and modern technology is *Ge-stell* and it is for that reason that "modern technology must employ exact physical science". Both Ellul and Heidegger accepted the mysteriousness of the origin of this essence.

My argument is that if we take a closer look at the transformation in the status of mechanics and its internal construction in the sixteenth century then we can locate the origin of the synthesis between science and technology *as the acceptance and dissemination of the precepts of mechanical realism.* In my view, the historical situation was the reverse of Ellul's interpretation. The universalist and humanist movement was restricted to an intellectual and religious elite but the confidence in and the value of the practical advances of the experimental philosophies were widely recognised. The Baconian dream was more deeply and widely entrenched than the philosophies of Descartes, Leibniz, Voltaire and Diderot. Ellul identified five factors leading to the transformation of seventeenth century civilization into the technical civilization of the nineteenth century. These were social plasticity, economic plasticity, population growth, the accumulation of diverse technical experiences, and the appearance of "a clear technical intention". Ellul defined "a clear technical intention" to be "a precise view of the technical possibilities, the will to attain certain ends, application in all areas, and adherence of the whole of society to a conspicuous technical objective."(1964, pp.52) I agree with Ellul that the above factors were essential for the development of the nineteenth century technological base and the technosciences. However, the technical imperative was present in European thinking from at least the sixteenth century onwards. In fact, we can see a "clear technical intention" in the writings of Francis Bacon, the practical interests of the Royal Society, and the efforts of the sixteenth century Italian mechanists and engineers. As Kuhn (1962, 1977) pointed out, the practical values of the new sciences were central to the whole enterprise from its onset. Craft practices and the innovation of novel tools and instruments were central to the work of Galileo, Descartes, and Newton. The technical imperative was present in the sixteenth century drive for the achievement of commercial, political, and military advantage in the competitive contexts of European ambitions. It may well have been a dream but the intention was there. The destining of modern technology had begun. We can readily reverse the order of rank in Ellul's argument (1964, pp.47-9) that the decisive condition for technique was the systematic disintegration of social groups and their replacement with atomistic individualism. The identification of "Man" as an isolated and rational individual is apparent in the writings of Descartes, Bacon, Bentham, Hobbes, and Rousseau. The focus upon material practices and social relations based upon their satisfaction of individual interests preceded the nineteenth century. This atomistic individualism was itself a consequence of the beliefs in the primacy of the techniques of rational and reasoned discourse and the unitary material relation between "Man" and "Nature" as disclosed by the mechanical philosophies.[21] It was itself premised upon an universalist conception of "Man" and the precepts of mechanical realism. The atomistic, state-governed, malleable, flexible, and individualistic society, that Ellul considered as a condition of technique, was itself a consequence of the conceptions of "Man" and "Nature" forged between the seventeenth and eighteenth centuries. These conceptions were a consequence of the technical imperative rather than its conditions. They were conditions for the mass transformation of society termed as "the Industrial Revolution" and the mass participation in the technical imperative to be presented as progress, social evolution, and human destiny. Ellul located the search for "efficiency", the demand for the "one best way to do work", in the nineteenth century. However, it was the mechanical realist metaphysics of the sixteenth and seventeenth century that proposed that there is one single most efficient mechanism in operation between any particular cause and its effect(s). That "most efficient mechanism" was termed as "the natural mechanism" and it was the allotted task of the natural experimental philosophies to find it for any particular cause-effect sequence. Thus mechanical realism provided the metaphysical foundation for the possibility of technique and provided the link between the natural mathematical sciences and the practical sciences.

[21] Lukacs termed this atomistic individualism of the post Renaissance as "an individual consciousness à la Robinson Crusoe". (1967, p.135).

The distinction between "pure" and "applied" science is *merely* the distinction between finding the "most efficient mechanism" and implementing it in productive practices. Once we address the extent that experimental physics interactively and reiteratively involves both the discovery and implementation of "the most efficient mechanism" in on-going research and technological practices, as I shall argue in the next two chapters, we can characterise experimental physics as internally both "pure" and "applied". In my view, this characterisation is as appropriate for the mechanical philosophies of the seventeenth century as it is for the physical sciences of the nineteenth century (and for the twentieth century as well) because both shared the same metaphysical precepts. It is merely the case that it is more obviously characteristic of the nineteenth century physical sciences and, as Ellul correctly pointed out, the nineteenth century required certain economic, social, and technological conditions before it could technoscientifically "flourish".

However, there was considerable equivocation, on Ellul's part, in his description of the relations between science and technology. He maintained (1964, p.88) the view that mechanical progress "is limited by the physical world". In his view, (1964, p.103) the drive for efficiency is the mobilisation of "the forces of nature" and the exploration of the atom was an "intervention into the inorganic world." He also insisted upon the fact that "The only thing that matters technically is yield, production. This is the law of technique; this yield can only be obtained by the total mobilisation of human beings, body and soul, and this implies the exploitation of all human psychic forces." (1964, p.324) and, yet, "The new milieu has its own specific laws which are not the laws of organic or inorganic matter... Man is still ignorant of these laws." (1964, p.429) Does this equivocation reveal an inherent contradiction in Ellul's thesis? How could science and technology be related in this way and have nothing in common with the natural world? Did Ellul take "the physical world" and "the inorganic world" to be distinct from "the natural world"? Unfortunately, Ellul did not discuss the relations between these "worlds" further. In my view, the equivocation in Ellul's thesis was a consequence of his rationalist account of mathematics and the character of science as mathematical, on one side, and the absence of any account of the technique(s) which provided a clear link between mathematics and technology, on the other. What was the scientific synthesis? How did science produce explanations? Ellul argued that the precision of any machine is only possible because of the elaboration of its design with mathematical rigor in accordance with its use but he did not provide any account of how this elaboration of its design could be performed. For Ellul, (1964, p.73) this meant that practical activity rejected "gratuitous aesthetic preoccupations" in favour of "the idea that the line best adapted to use is the most beautiful". It was necessity that characterised the technical universe because "everything must accommodate itself to its mathematical certainty" (1964, p.116) but he did not provide any account of how mathematics became bound up with the technical imperative and conceptions of "efficiency". This omission lead to the considerable equivocation on his part which can be seen in his stance that modern science depends upon technique whilst maintaining the "traditional view" that *somehow* technology is "applied science" because it is mathematical. For example, Ellul wrote, "technique is universal in its manifestations. It is devoted, by nature and by necessity, to the universal. It could not be otherwise. It depends upon a science itself devoted to the universal and becoming the universal language understood by all men. We need not belabour the fact, which everyone recognises, that science is universal. And this fact in turn leads of necessity to the technical universalisation which stems from it." (1964, p.131)

However, I wish to criticise "the fact" that science is universal. I accept that the reification of mathematics, as something referent to objective, universal, and eternal truths, has been inherent to human thinking (in both occidental and oriental cultures) since antiquity. The mathematical character of post-sixteenth century physics is evidently dependent upon the recognition that mathematics is universal. However, this raises central questions for my argument. What is the object of the mathematical descriptions of mathematical physics? Which technique(s) linked mathematics and technology? I shall argue below that the object of mathematical physics has been, since the sixteenth century, the mechanical motion of machine performances. It was the technique of applying Euclidean-Archimedean geometry to the problems of mathematically describing the six simple machines that linked mathematics and mechanics. The metaphysical precepts of mechanical realism allowed these mathematical descriptions to be presented as representations of "natural laws" and opened the way for the possibility of using mathematically described mechanisms to explain the occurrence of natural phenomena. This metaphysics is the root of both modern physics and modern technology. Technique is limited by "the physical world" and intervenes in "the inorganic world" by mobilising "the forces of Nature". These "worlds" are nothing more that the whole complex of technical ensembles of machines, in which any mobilisation of "forces of Nature" is the non-linear interactions that occur during the attempts to integrate novel machines into this complex. It does not necessarily have anything to do with the natural world at all! This complex is itself only a small part of the real world (which I take to contain both natural and artificial entities). If we are to understand the origins of physics as a technoscience, we must inquire into how the massive reduction of the ontology of the real world to an innovated collection and ensemble of machines was metaphysically founded. This involves an inquiry into the sixteenth century use of mathematics and the science of mechanics.

Mathematical Projection:

Unfortunately Ellul did not provide us with any details about his understanding of the mathematical sciences. However, for Heidegger, the mathematical aspect was central to his understanding of physics and the metaphysics upon which it was founded. Heidegger analysed the essence of modern science as the transformation of fundamental concepts that constituted the "scientific revolution" of the fifteenth to seventeenth centuries. What was the transformation of fundamental concepts that occurred during this period? How do modern sciences differ from ancient *episteme* and medieval *scientia*? How was this transformation possible?

In *What Is Metaphysics?* Heidegger (1999c, p.83) considered modern science, as distinct from ancient *episteme* or medieval *scientia*, to have an essence because "in a way peculiar to it, it gives the matter itself explicitly and solely the first and last word."[22] What is the way peculiar to it? What is "the

[22] First published in 1929.

matter itself"? How does this way give "the matter itself" words at all? These questions were central to all of Heidegger's efforts to understand the essence of modern science and its "special relation" to the world. Heidegger examined this special relation, and the human stance that guides and sustains it, by attending to *how* modern science relates to the world and *what happened* in order to attain that relation. The human stance that guides and sustains science is one of *pursuing science*. In this pursuit, the human being, as one being among others, "irrupts" into the whole of beings in such a way that, in and through this "irruption", beings show themselves as what and how they are. What is the character of this "irruption"? How does it help beings "show themselves as what and how they are"? It was essential to Heidegger's approach that *human beings are only able to pursue science by anticipating the nature of the being that they pursue*. Human beings could not begin (or end) the pursuit without anticipating the conditions under which it could be considered to have been successful or have failed. How and what do human beings "anticipate" when they pursue science?

Heidegger (1999b, p.272) took it for granted that measurement, experimentation, the use of mathematics, and relating conceptual and material practices, are characteristics of modern science, but argued that these characteristics should not be taken to be the essence of modern science.[23] Heidegger considered experimentation, as a means of acquiring information and testing cognitions, via a definite ordering of things and events, to be a basic kind of experience and activity involved in all craft work, tool use, and material practices. This was familiar to ancients and medievals alike. Heidegger did not give any supporting examples to support this claim. However, contemporary historians of science and technology have provided historical examples of measurement, experimentation, the use of mathematics to analyse natural phenomena, and conceptualised material practices, from ancient and medieval periods that discredit the "traditional view" that these facets began during the "scientific revolution".[24] Ancient, medieval, and modern sciences involved working with mathematics and measurements. The use of facts, experiments, measurements, and mathematics, was not the fundamental novelty of the emergence of the modern sciences. These were not the fundamental characteristics of the novelty of the "scientific revolution". Modern science is different from its predecessors because of *the way* that it measures, experiments, uses mathematics, and conceptualises. The fundamental novelty of the modern sciences consisted in *how* facts, experiments, measurements, and mathematics were used. Heidegger's analysis of modern experimental sciences raised crucial questions. How were the experiments set up? What was the intent with which they were undertaken and in which they were grounded? How was the manner of experimentation *connected* with the conceptual determination of the facts? How were the concepts applied? What preconceptions were made about the phenomena in the setting up of the experiment? How were the practices of calculation and measurement applied and carried out? How were these mathematical and measuring practices used to determine the objects of investigation?

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[23] Original edition: *Die Frage nach dem Ding*, Tublingen: Max Niemeyer Verlag, 1962, pp. 50-83

[24] For examples, see Clagett (1959a,b), Laird (1986, pp.44-5), Lindberg (1982), Murdoch and Sylla (1978), and Torrance (1999, p.577).

Heidegger (1999b, pp.273-8) characterised one fundamental event in the pursuit of modern mathematical science, in the work of Galileo, Descartes, and Newton, to be *mathematical projection.*[25] Heidegger analysed this in two related ways by describing (1) what mathematical projection consisted of and how it unfolded its essence; and, (2) how it became established in a certain direction. The meaning of "mathematical projection" was not to be taken from mathematics itself because mathematics is only a particular formulation of the mathematical. The word "mathematical" referred to the way that something is learnt, rather than merely using mathematics, and the word "projection" referred to the fundamental presuppositions and expectations that anticipated the phenomenon. Galileo conceived the motion of each and every body as having one "basic blueprint" according to which motion was nothing more than the determination of geometrical points in uniform space and time. This "basic blueprint" circumscribed its realm of application as both universal and uniform. Heidegger noted (1999b, p.289) that the conception of a body moving under uniform rectilinear motion, as posited by Galileo and Newton, was one that did not correspond to any experienced motion of a body and there is not any conceivable experiment which would bring such a body into direct perception. Heidegger noted the irony in the positivistic rejection of medieval scholasticism and *scientia*, as merely dialectical and poetic, in favour of a science concerned with an imaginary and unexperienced thing such as uniform rectilinear motion. How could a science, supposedly based upon experience, be founded upon a law that describes something that does not exist and demands a fundamental representation of things in contradiction to experience?[26] Heidegger presented (1999b, pp.291-3) the essence of mathematical projection as a conceptual project of conceiving the essence of phenomena that skips over the phenomena and opens a domain where facts can show themselves. He used the term "skip over" to focus on the way that modern mathematical physics does not actually attend to the phenomena. In my view, Heidegger intended a double meaning to this term. On one hand he intended the connotation of "brushing the phenomena aside" and on the other hand intended the connotation of rapidly (and lightly) stepping over appearances to reach "their essential reality". For both connotations the notion of the phenomena as being an obstacle or a hindrance, which was all too easily avoided by modern mathematical physics, should be read into "skips over the phenomena". According to Heidegger, Galileo and Newton could not observe uniform rectilinear motion because such a motion does not occur. They started with an attendance to the phenomenon of motion but "skipped over" it in order to conceive of natural motion as uniform rectilinear motion. This project posited that phenomena were to be conceived of in certain ways, and what, and how, they were to be evaluated was brought to the

[25] Heidegger characterised modern science in terms of two other fundamental events: research and on-going activity. I shall discuss these in the next chapter.

[26] It could be argued that we could travel into the vacuum of space and put Newton's First Law to direct experiential test. There are two problems with this argument. Firstly, Newton's First Law was widely accepted 250 years, or thereabouts, prior to our technological ability to perform this experiment and we can not claim that experience was a criterion for its acceptance. Secondly, even if we were to perform this experiment, how we could *prove* that the body was *in fact* moving in a straight line?

phenomena. It was axiomatic and, by expressing physics and cognition in terms of fundamental propositions, the cognition that was taken and posited in the mathematical project was of such a kind as to set things upon their foundation in advance. As axiomatic, mathematical projection anticipated the essence of things and sketched the "basic blueprint" of the structure of everything, and its relation to every other thing, in advance. This basic plan provided the measure for laying out the circumscribed realm of Nature, as the context for uniform and universal motion in space and time, as outlined in the axiomatic project, which would *in the future* determine which bodies could be a part of it and anchored in it. Henceforth, natural bodies could only be what they were shown to be within this projected realm. This realm of Nature also required a mode of *access* appropriate to its axiomatic predetermination. How things were to be shown was prefigured in the project and, therefore, the project also determined the mode of experiencing and studying the phenomena. Things could only be shown in the relations of positions in space, and time, and as measures of mass and force. The project established a uniformity of all bodies according to relations of space, time, and motion; it also required, and made possible, a uniform measure as an essential determinant of things, i.e. numerical measurement. Inquiry was predetermined by the outline of the project in order to allow a line of questioning to be instituted in such a way that it posed conditions *in advance* to which Nature could answer one way or another. Upon the basis of the mathematical, the *experientia* became the modern experiment, and modern science is experimental because of mathematical projection. The mathematical projection of Newtonian bodies lead to the development of mathematics (in the narrow sense). The new form of modern science did not arise because mathematics became an essential determinant but, on the contrary, the use of mathematics was a *consequence* of mathematical projection. The founding (and application) of analytical geometry by Descartes, infinitesimal calculus by Newton, and differential calculus by Leibniz, were only possible because of the projection implicit from the onset.

Heidegger argued this project was metaphysically established, as the definition of modern metaphysics, in the work of Descartes. Descartes posited that clear and insightful *intuition*, or certain deductions, are the routes to knowledge, and also posited that method is necessary for us to have truths at all. This method was to consist in the order and arrangement upon that which "the sharp vision of the mind" is to be directed if truth is to be discovered. If mathematics, in the sense of *mathesis universalis*, was to ground and form the whole of knowledge then special axioms were required. These were to be intuitively self-evident and established *in advance* what constitutes being and from where, and how, the essence of being is to be determined. The basic mathematical projection was to be based upon its own foundation, *as a fundamental principle*, and be indubitable. Heidegger defined the essence of the mathematical according to the following general characteristic: it takes and gives to itself cognisance of something as a cognisance that it already had and brought to the experience of learning. The mathematical had the original meaning of learning what one already knows. How is mathematics and the mathematical connected? Heidegger's definition of "the mathematical" began with its etymological stem in ancient Greek. He translated *ta mathemata* to be "what can be learnt and, at the same time, what can be taught", *mathanein* as "to learn", and *mathesis* as "the learning and the teaching". The two-fold meaning of *ta mathemata* was to teach and to learn in a broad and essential sense (and not the narrow and trite sense of schools and scholars). Heidegger understood *ta mathemata* in terms of his understanding of what is involved in truly learning something or truly teaching something. True learning does not occur by merely being instructed that something is the case. It occurs *when the student learns for him or herself, in terms of his or her own experiences*, what the teacher is offering. Learning is a form of taking, self-giving, and is experienced as taking what one already has. It involves realising for oneself what is being taught. Teaching involves letting the students learn for themselves by bringing them to the point of learning by bringing to the fore what the students are already capable of learning for themselves. This way of learning is determined by what is brought to bear by the learner upon the phenomenon in question. For Heidegger, number was the most familiar form of the mathematical because numbers are "the closest to that which we recognise in things without deriving it from them" (1999b, p.227). Heidegger used the number "3" as an example. One cannot teach children the number "3" merely by showing them three chairs, or three apples, or three cats, and instructing them to see the unifying cognition of three things. Children must recognise that for themselves. Number is the most familiar example of the mathematical because it is the most readily learnt and taught. Other things are simply more difficult for children to learn for themselves, and, consequently, more difficult to teach. Recognition of one's own reflection in a mirror, one's own mother, that other people have feelings, acceptance of one's own mortality, how to read and write, and many other things that are not related to mathematics, would also be examples of the mathematical.

"[O]ne must grasp that the fundamental condition for the proper possibility of knowing is the knowledge of the fundamental presuppositions of all knowledge and the position we take based on such knowledge. A knowledge which does not build its foundation knowledgeably, and thereby notes its limits, is not knowledge but mere opinion." (p.278)

For Heidegger, the numerical was something mathematical in this sense. Citing Galileo's famous (and perhaps mythical) experiment of dropping weights from the tower of Pisa, Heidegger argued that onlookers disagreed with Galileo's interpretation of the same phenomenon (p.290). They saw the weights hit the ground at slightly different times whilst Galileo triumphantly upheld his view that they hit the ground at the same time. Kuhn (1962) and Feyerabend (1975) gave a similar interpretation of Galileo's experiment in terms of the "theory ladeness" of observation. Galileo conceived the motion of all bodies as rectilinear and uniform (once ever obstacle was excluded) but that it also changed uniformly when an equal force affected it. This was how Galileo could conceive of the motion of a body thrown onto a horizontal and smooth plane as being uniform and perpetual if the plane was extended infinitely. Heidegger pointed out that Galileo used this thought experiment to present his conception of the motion of a body in such a way as to allow the reader to cognate it for him or herself. Heidegger compared this to Plato's characterisation of *mathesis* in *Meno* (85d) as "taking the knowledge from out of himself". Galileo had provided an *a priori* conception of what should be universally conceived about each and every body: no bodies are special, every place is like every other, no motion is special, and every force is to be understood only in terms of the change in motion it caused. Galileo had conceived the determination of each and every body as having one "basic blueprint" according to which the natural process was nothing more that the space-time determination of the motion of geometrical points. Furthermore, this "basic blueprint" circumscribed its realm of application as both universal and uniform.

What are the limits and justification of mathematical formalism in contrast to a demand for an immediate return to intuitively given Nature? The particular discipline of mathematics is a special form developing from the mathematical, but, argued Heidegger, we need to grasp the mathematical at a deeper level. For Heidegger, every kind of thinking was a consequence of "a mode of historical Dasein" and, as such, was a consequence of fundamental positions taken towards Being and towards the way in which beings are manifest as such, i.e. towards truth. What new fundamental position of Dasein showed itself in the rise of the dominance of the mathematical? For Heidegger, this new fundamental position was a spirit and formulation of freedom (against the Church, faith, and Aristotelian dogma) to have new experiences. In the mathematical project an obligation to the principles, demanded by the mathematical project itself, was developed and self imposed. How did the mathematical project, according to its inner direction, drive towards an ascent to a metaphysical determination of Dasein? Modern natural science, mathematics, and metaphysics sprang from the same root of the mathematical (in the wider sense). [27] In my view, it is this characteristic of modern mathematical science that has led some philosophers of science to argue that the metaphysical

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[27] The historian W.P.D. Wightman (1962) presented a similar (but broader) view of the whole Renaissance. He argued that it was, in fact, the whole conception of "the scientific revolution" *as a revolution* that was the novelty of the late sixteenth century. He was also aware that many of the ideas of "the so-called scientific revolution" were, in fact, rediscoveries of the ideas of the Medievals and Ancients. He argued (p.4) that William Whewell's oft quoted idea that the mechanical sciences and arts "had lain in Stygian darkness for roughly a millennium and had been revived in the second half of the sixteenth century " was *itself* an invention of the late sixteenth century. Contrary to this myth, Wightman argued that there was considerable continuity between the development of the arts (including literature, fine arts, and sciences) throughout the pre- and post fifteenth century periods. For Wightman, "the Renaissance" was invented during the sixteenth and seventeenth centuries through a critical reflection upon the past that, after using the efforts of its predecessors and pronouncing their rejection, presented itself as "coming out of itself". In many respects, the novelty of this period was the presentation of itself as something novel.

foundations of modern physics are platonic. [28] It has been argued that Galileo was a Platonist because his new science was based upon an interrogation of Nature that was formulated in terms of geometrical language rather than observations and experiences based on ordinary language. As Heidegger, Kuhn, and Feyerabend argued, this new science was not based on common sense, observation, and experience. Galileo's theory of motion was based on a geometrization of Nature and the concrete, qualitatively differentiated, lived-world experience of distances was replaced with the homogeneous and isotropic abstract space of Euclidean geometry. Galileo de-inscribed ordinary perception from experience and, in its place, inscribed Euclidean geometry upon it. It is supposedly this "Platonism" that placed Galileo's physics in direct opposition to the physics of Aristotle.[29] For the Aristotelian, this mathematical approach to the presence of phenomena, replacing real bodies moving in real space by mathematical bodies moving in mathematical space, was something that was fundamentally unacceptable and has been taken to the central point of incommensurability between the two physics.[30] The question about the role and nature of mathematics is supposedly the central point of opposition between the new and the old physics. However, Galileo's attempts at mathematical inscription of experience involved more than a platonic istoria at the indubitability of geometry. For Galileo, these deductions had to be proved by experimentation – by mathematically describing mechanisms – and it is this methodological demand that makes his natural philosophy more indebted to Archimedes than it was to Plato.[31] In my view, Galileo's affirmation of geometry as being "the language of Nature" is insufficient to qualify him as a Platonist. Nowhere in Galileo's works can we find an inquiry into

[28] Cf. Koyré (1992, pp.16-43), Burtt (1954, pp.40-7), and Whitehead (1925, ch.1-3). Burtt and Whitehead argued that the mathematical essentialism of Copernicus, Kepler, Galileo, and Newton, was the result of an emergence of neoplatonism in Renaissance Europe. Koyré, following Burtt, argued that Galileo was a Platonist because Galileo held *a priori* that "the book of Nature" is written in mathematics.

[29] See Koyré (1992: pp. 28-43) for his discussion of Aristotelian objections to the geometrization of space.

[30] Aristotle did permit mathematics a role in *technai* such as astronomy, optics, and music. See *Physics* II.2.194a7-11; *Post. Anal.* I.7.75b14-20; and *Meteo.* III.3-5. See also Heath (1949).

[31] Koyré was aware of Galileo's Archimedean inspirations. I agree with Koyré's view that "The true forerunner of modern physics is... Archimedes." (p.22), for reasons that shall become apparent. However, I disagree with his view (p.22.fn.2) that "the sixteenth century, at least its latter half, is the period of the reception of the study and of the gradual understanding of Archimedes." The reception and gradual understanding of Archimedes had been occurring since, at least, the thirteenth. Furthermore, Koyré described Archimedes as a Platonist without evidence to support this claim apart from Archimedes' passion for geometry. It seems that, by Koyré's criteria anyone who considers geometrical proofs to be universal, eternal, and complete is a Platonist. My view is that this is not good enough.

knowledge, wisdom, virtue, justice, and the immaterial and unchanging form of the Good.[32] A commitment to the utility of mathematics in describing specific natural phenomena, such as moving bodies, is not sufficient, in itself, to qualify as a Pythagorean, Platonic, or neoplatonic metaphysics.[33] Metaphysics in the sixteenth and seventeenth centuries was not defined in terms of a positivistic definition as being a collection of unconscious presuppositions and dispositions (or a paradigm, in one of Kuhn's sense of the word.) This would take the meaning of "metaphysics" out of historical context.[34] In the sixteenth and seventeenth centuries the aim of metaphysics was to argue for, or assert, fundamental *a priori* principles, that were reflectively explicated and put forward with conviction in order to invoke conviction. Metaphysics constituted a formal philosophical position, not a set of unarticulated values and beliefs, regarding the nature of Nature.[35] Arguably, the reason for the view that modern physics was based upon a Platonic metaphysics was probably based upon a positivistic interpretation of Plato's *Timaeus* Dialogue. In this dialogue, Plato used the analogy of the craftsman in the story of the origin and form of the *Kosmos* through the work of a divine craftsman (the Demiurge). Plato also used the metaphors of "a shaking machine" to describe the ordering and mixing of the elements (53a4), and "natural mechanism" in the description of the digestion of food (80d1-81a1). The character Timaeus also proposed that an understanding of the *Kosmos* required an understanding of mathematics. It is this proposition that taken to be the opinion of Plato. However, there is no evidence that Plato intended this dialogue to be a vehicle for his own cosmological opinions and, in my view, we cannot know to what extent, if any, the speech given by Timaeus represented the opinions of Plato. Especially given that even the character Timaeus distances himself from the literal truth of his speech by emphasising that it is only a likely story (29d1). One may equally speculate that it is more likely that Plato situated this dialogue within the larger project of conveying general points about the nature of philosophical discourse. In this context it should be read as the middle dialogue on the nature of philosophical speeches between *The Republic* and *Critias*. Timaeus closely related *phusis* and *techne* in his description of the *Kosmos*. *Phusis* was without any internal power to produce its own order, form, or being, and required input from the *techne* of the Demiurge in the cosmic order in which *phusis* was

[32] In my view, this is a necessary (but not sufficient) criterion for a philosophical position to be identified as platonic.

[33] Cf. Hatfield (1990) for his argument in support of this point.

[34] I agree with Hatfield's argument on this point. I would also like to add that, on Hatfield's criterion for classifying a position as metaphysical, we would be using the term anachronistically if we characterised Plato's position as metaphysical for two reasons. Firstly, the first use of the term "metaphysics" was to entitle the book of Aristotle that followed the *Physics*. Secondly, Plato's own use of mathematics in discussions and arguments were (arguably) designed to elucidate and clarify Socrates' arguments about the nature of the forms and how we could come to know them.

[35] That is not to say that metaphysical positions were not based on unconscious presuppositions but it does mean that these presuppositions were not *themselves* metaphysical positions.

immanent. It was this view of the *Kosmos* that had considerable commonality with the metaphysical arguments of Descartes and Gassendi, for instance. This was the opposite of Aristotle's argument in the *Physics* that the function fulfilled by the Demiurge was immanent in *phusis*, as an intrinsically divine principle of ordered change, and hence it did not require any input from an external Deity.

Hatfield (1990) argued for an important distinction between the metaphysical arguments of Descartes and Leibniz, for instance, and the geometrical arguments of Galileo and Copernicus. He considered the former as metaphysical, in terms of their own period, the latter as an extension of already established mathematical practices, and argued for the importance of recognising that there were both metaphysical and non-metaphysical styles of argumentation in the sixteenth and seventeenth centuries. This recognition is important. If all the styles of argumentation are anachronistically treated as metaphysical then the influence of the practicality of mathematical practices upon the development of modern science tends to be overlooked. The fact that an author used mathematical arguments is not sufficient grounds for attributing platonic metaphysics to him/her; there are many non-platonic European traditions that used mathematical arguments (including the Ptolemaic astronomers, presocratic geometers, cabalists, alchemists, and members of the Hermetic tradition.) Galileo was more indebted to Euclid and Archimedes than Plato. In addition, Hatfield argued that there is scant textural evidence for the view that Galileo's (and Copernicus') arguments were based on Platonist or neoplatonist metaphysics. He cites this scant textural evidence for the Platonic Galileo as the numerous allusions to Plato in Galileo's dialogues, reference to the theory of recollection expounded by Socrates in *The Republic*, the choice of dialogue style for his major works, allusions to the socratic method, and the emphasis on geometry as a route to knowledge. Galileo's allusions to Plato and his choice of the dialogue as the style for his major works could be read as a commitment to Platonism, but they could also be read as simply the use of allusion and style for rhetorical and elucidatory purposes. Hatfield noted (1990, p.124-5) that "the characterization of Plato as a supporter of geometry or mathematics is thrice put in the mouth of Simplicio, and once in the mouth of Sagredo, but never in the mouth of Salviati, who simply defends the importance of geometry and geometrical demonstration, saving his praise for Euclid, Archimedes, and Copernicus." When Salviati discusses *quoddam reminisci* (reminiscence) he refers to previous experience of everyday objects or events, appealing to Simplicio or Sagredo's ability to imagine and think about these objects or events *geometrically*. He does not appeal to a recollection of a direct apprehension of the eternal Forms that occurs during the period between death and rebirth.[36] Salviati argues for "common sense" to be guided by geometrical reasoning, images, figures, and diagrams. Geometry was used to order the imagination of the reader with the purpose of demonstrating the applicability of geometry to everyday experience of certain objects or events. As Hatfield remarked: "Salviati's remarks on geometry appear as the remarks of one who is teaching the value of the mathematical approach to nature through instances of the practice,

[36] For example, see *Two World Systems* (Drake trans.) pp.190-1. Hatfield (1990, p.122) interpreted Salviati's responses to Simplicio's allusions to Plato's reminiscence as being openly ironic.

rather than the remarks of one who has a Platonic appreciation of pure geometrical intuition."[37] Hatfield argued that Galileo's project involved the development and extension of mathematical practices. He offered examples of a method to solve specific kinds of problem. In Hatfield's view, Galileo's approach was that of presenting a series of innovative mathematical exemplars that could be used to solve specified problems. Galileo's dialogues were those of a practitioner teaching his practice by reference to a specified set of problems and the demonstration of their solution. As Hatfield remarked,

"Although [Galileo] looked to mathematics as a model of knowledge, he neither sought an *a priori* insight into the plan of a geometrizing deity nor extended this model into a rational, intellectualist account of knowledge in general... his mathematical approach was taught through the examination of instances of its application, not through the presentation of a codified set of precepts." (1990, p.138)

It is on this point that I disagree with Hatfield and agree with Heidegger. I accept that Galileo extended mathematical practices but he also presented a codified set of precepts as well. By focussing on the mathematical practices to the exclusion any substantive metaphysical and ontological commitments on Galileo's part, Hatfield has overlooked the realism inherent to Galileo's physics. Galileo was neither an instrumentalist nor a pragmatist. Galileo did more than draw a distinction between qualities that afforded mathematical description and qualities that did not. For Galileo, length, weight, and number, the measurable qualities were *real*, whereas qualities such as taste, odour, and colour, were to be explained away as *illusionary*.[38] This distinction – later termed by Locke to be one between 'primary' and 'secondary' qualities – shows that Galileo was doing more than argue for the extendibility of mathematical practices to observation. Galileo was constructing experience in terms of features that were supposedly real, or natural, and features that were the responses of sense organs to real features.[39] Of course, this construction had a primary methodological value because it allowed a problem to be broken down into simple parts, but it signified more than this in Galileo's physics. For Galileo, taste, odour, colour, and touch, were "no more than mere names", whereas size, shape, weight, and motion, were quantities that were properties of external bodies that would remain even "if ears, tongues, and

[37] Hatfield (1990, p.125). Hatfield was aware that Galileo was more an Archimedean that a Platonist. It is also worth noting that Socrates was dismissive of astronomy as a worthwhile pursuit (as well as the *phusicoi* in general). In my opinion, the application of geometry to mechanical problems as providing essential knowledge about the world would have received short shrift from Plato as the activity of a foolish *technite* and not a road to wisdom.

[38] For Galileo's argument for the distinction between real and nominal qualities see *The Assayer* pp. 308-13.

[39] For examples, see Galileo's treatment of music in *Two New Sciences* pp. 98-104 and his treatment of heat in *The Assayer* pp.308-13.

noses were taken away".[40] Galileo overtly argued for a realist interpretation of such quantities and, *by Hatfield's criterion*, offered a substantive metaphysical position as a starting point for his physics. He articulated assumptions about Nature and presented a method by which Nature could be investigated; his physics involved metaphysically directed practices. It was as a form of mathematical projection that Galileo extended mathematical practices. The style of Galileo's arguments, throughout his works, was that of using mathematical arguments to show how "knowing for oneself" was central to the project of reading the book of Nature. This involved the assumption, as a starting point, that Nature is comprised of mathematical properties that can be isolated and treated as interacting components in a dynamic system that could be explored by geometrically describing phenomena in terms of mechanisms. Furthermore, for Galileo, if one truly understood any phenomenon then one should be able to construct a machine to reproduce that phenomenon. The mechanisms at work in the construction of the mechanical model are *literally* those of Nature. The mechanical was to be taken literally as an embodiment of mathematics in the world. This is evident from Galileo's use of a pendulum to demonstrate his theory of motion, his use of an astronomical sphere to demonstrate his theory about the Sun's rotation, and steelyards and balances to demonstrate his theory of free fall.[41] In the metaphysics of Galileo, mechanical realism had emerged into seventeenth century as a substantive metaphysical position and constituted a set of precepts.[42] The transition between the Euclidean mathematical Aristotelian-Archimedean tradition of mathematical mechanics and the development of mathematical natural science required a set of precepts in order to appeal to a generalised principle of operation in Nature in order to correlate the motion of bodies, and their properties, with measurements.[43] Furthermore, by restricting the classification of the real to that of the mechanical Galileo's mechanical realism was a *reductive* mechanical realism. This was a precursor to the mechanical philosophies of the seventeenth century that Hatfield considered as metaphysical.

In Galileo's work, the "mathematical" element was used to reflect what Galileo wanted to learn from phenomena and, consequently, reflected his anticipations. Galileo's science was as abstract as the scholastic natural philosophies that he criticised for their abstractness. Ancient, medieval, and modern sciences all involved the utilisation of mathematics, facts, and concepts. What differed was the way that these facts were conceived and how mathematics and concepts were used and established. The positivistic attempt to distinguish modern from pre-modern sciences, by describing the former as based on facts, is inadequate. Positivistic science is only capable of performing "average and supplementary

[40] *Assayer.* p.313

[41] Galileo (1960) on pendula pp.152-3; on the astronomical sphere pp.348-9; on steelyards and balances pp.213-4.

[42] I hasten to add that although the content of mechanical realism is explicit in Galileo's work it was not named as 'mechanical realism'. Galileo's term for this metaphysics was 'science'.

[43] On this point I agree with Strong (1966, p.3). However, Strong did not account for the use of machines or mechanical devices in the rise of mathematical natural science and, consequently, this generalised principle of operation remained explained.

work" (in Heidegger's words, 1999b, p. 271) and "normal science" (to use Kuhn's term). Novel research involves the fundamental creation and extension of new concepts rather than collecting *mere facts* because a fact is only what it is in the light of the fundamental conception. For Galileo, this fundamental conception was encapsulated in the precepts of his metaphysical mechanical realism. However, this raises the question of how he managed to conceive those precepts. From what resources did he draw upon? From where did his anticipations arise? How did he draw up his "blue print" which he mathematically projected over his experiences of natural phenomena? What was the content of his "mathematical projection"?

The Science of Mechanics

Archaeologists have provided considerable artifactural evidence of ingenious innovations in ancient civilisations.[44] Several ancient texts dealing with the geometrical and general principles of craft practices and mechanics were available, translated, and studied during the medieval period. For example, Vitruvius' (c. 1BC) *De Architectura* (on the theory and practice of architecture and the large scale management of craftsmen and labourers); Heron of Alexandria's (c. 1AD) detailed works on pure mathematics, physics, mechanics, surveying instruments, and practical engineering.[45] Frontinus' (c. 1AD) *De Aquis* (on the engineering and distribution of water supplies); Plindy's (c. 1AD) *Naturalis Historia* (which includes sections on artifice and the mathematical treatment of mechanisms); and, Pappus (c. 4AD) wrote on several problems of mechanics.[46] All of these works contained systematic collections of Euclidean geometrical treatments, inventions, designs, experiences, and accounts of established practices. If we consider technology to be the *logos* (rationale, accounts, principles) of *techne* then all of these works are technological. They do not merely constitute collections of accounts of trial and error tinkering.[47] The cultural dissemination of mechanics was accelerated by the invention and dissemination of the printing press as the mechanical arts were explicated in writing, including mathematical and illustrative diagrams, as well as rationalised and associated with the ancients through

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[44] Cf. De Santillana (1961: pp. 276-79) for discussion of Hellenistic and Roman engineering and mechanics; Rostovtzeveff (1941) for details about Egyptian (c.18BC) automatic irrigation systems; Winton (1962) for details about ancient Babylonian (c.250BC) batteries used for copper and silver plating techniques; Temple (2000) for details about ancient Egyptian, Hindu, Cathaginian, African, and Greek optics; Price (1959) for details about an ancient Greek (c.82BC) mechanical planetary cycle and retrograde motion calculator.

[45] His mathematical work was Euclidean, used Archimedes' proofs and mechanical method, and included *Pneumatics, Mechanica, Catopica* (theory of mirrors), *Metrica, Dispotra* (theory and practice of surveying), *Automatopoietike* (the making of automata), *Definitions, Geometrica*, and *Stereometrica* (solid geometry).

[46] Cf. Dugas (1955, pp. 33-5) for Pappus' treatment of the problem of the inclined plane.

[47] As Wolpert (1992) would have us believe about almost every productive practices prior to the sixteenth century.

geometry in order to give them status of being "sciences".[48] This involved the innovation and dissemination of new *inscriptive techniques* that, in turn, required the modification of printing technology to cope with these new forms of technical and mathematical writing. Once the know-how of craftsmen and practitioners was presented in terms of mathematical and rational principles it was transformed into "true knowledge". When coupled with the patronage of political and military powers this elevated the social status of the mechanical arts and prepared the way for the experimental and mechanical "natural" philosophies of the sixteenth century to achieve mechanical leverage into the workings of Nature. The experimental and mechanical sciences of the sixteenth and seventeenth centuries grew out of the contemporary mechanical arts and mathematical sciences of the fourteenth and fifteenth centuries. The artisan had a central role in the emergence of experimental philosophy because, as Bennett put it, the "experimental philosophy, given its methodology of testing hypotheses by manipulating mechanical devices, must be said to have appropriated both values and specific knowledge from the mechanical arts." (1986, p.2) Once the status of mechanical invention had been transformed from a craft to a science, via mathematics and the patronage of elites, the conditions were ripe for the formal construction of the science of mechanics.

White argued that during the thirteenth century there emerged both generalised concepts of mechanical power and the view that Nature was "a vast reservoir of energies to be tapped and used according to human intentions."(1962, p.134) If White was correct then the conception of Nature as a resource, a conception that Heidegger considered to be the essence of modern technology that distinguished it from ancient handicrafts, emerged 300 years before the "scientific revolution" and over 500 years before the nineteenth century "industrial revolution". White argued between the thirteenth and sixteenth centuries there were widespread innovations in civic, military, and economic technologies, as Europe began its expansion of political, economic, and military powers. This expansion required more resources and the continuing innovation of machines and techniques to enhance productive, explorational, military, and civic power. In his view, the sixteenth century development of technologies was a continuation of the post thirteenth century "period of decisive development in the effort to use the forces of nature mechanically for human purposes."(1962, p.79) Clagett argued that it was the continuing medieval innovation of technologies and the fascination with mechanism that contained the seeds of the sixteenth century development of mechanics and the new physics.[49] He argued that the physical concepts used by Galileo, Descartes, and Newton, had significant continuity with those used in ancient and medieval studies of mechanics. Medieval mechanics – largely based on Pseudo-Aristotle's *Mechanica*, Heron's *Mechanics*, and Archimedes' demonstrations – were continually modified and developed in such a way that the points of criticism raised in the fourteenth and fifteenth centuries became the points of departure for the mechanics of the sixteenth and seventeenth centuries. (1959a, p.41)

On Clagget and White's accounts, the mechanics of the sixteenth and seventeenth centuries

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[48] Long (1997, p. 29). Also see Eisenstein (1979, pp. 520-74.)

[49] Clagett (1959a). See also Clagett & Moody (1952).

was the culmination of medieval efforts rather than the radical break that the advocates of the "traditional view" have assumed. The sixteenth century science of mechanics had its origins in the mathematical treatments of mechanical devices and the culture of technological innovation that occurred from, at least, the thirteenth century onwards. From the mid-thirteenth century many treatises appeared that focussed on the problems of kinematics and dynamics for mathematical and philosophical treatment. By the fourteenth century there were many books on the subject of the application of geometry to the problems of motion.[50] The thirteenth century mathematician Jordanus de Nemore, in his book *De rationale ponderibus*, used both Archimedean static proofs and Arabic derivatives to tackle the problems of the balance, weights, levers, and the problem of geometrically dealing with the problems of motion. John Buridan's fourteenth century book *Questiones super libris quattuor de caelo* included discussions of impetus theory, the possible rotation and motion of the Earth, the general law of leverage, the solution to the problem of the inclined plane, and the equilibrium of connected weights.[51] Both Nemore and Buridan tacked problems that were to become central to Galileo's work during sixteenth and seventeenth centuries. Of course the objection may be raised that these early efforts were based upon completely different conceptions of motion and matter. Indeed they were. Buridan's notion of "impetus", for example, has no correlate in Galileo's mechanics and, in terms of modern mechanics, the early efforts made significant errors in their treatments of even simple mechanical devices. However, this is irrelevant for the question of whether Galileo's mechanics was a culmination of earlier efforts. What we see in the pre-sixteenth century efforts was *the attempt* to describe the motions of simple mechanical devices in terms of Euclidean geometry. This set down the template for subsequent efforts.

The most influential ancient sources for the template for the sixteenth century science of mechanics were the works of Euclid, Archimedes, and Pseudo-Aristotle. Pseudo-Aristotle's *Mechanical Problems* was possibly written in the 4th century BC by a student of Aristotle called Strato. The only certainty regarding the authorship of this work is that it was not Aristotle. In the *Mechanical Problems* the geometrical treatment of all the simple machines were reduced to a single problem: the properties of the balance were related to those of the circle and the properties of the lever to those of the balance. All the motions in mechanics were reduced to consequences of the properties of a lever and the circle. Archimedes' works had a profound influence on Medieval and Renaissance mechanics, as they became available to medieval scholars from predominantly tenth century Arabic sources and were translated into Latin from the thirteenth century onwards.[52] Roger Bacon, in the thirteenth century, invoked Archimedes against those who did not "dare to know" and Commandino, in sixteenth century, wrote, "with respect to geometry no one of sound mind could deny that Archimedes was some God."[53] Leonardo da Vinci studied both Archimedes' mathematics and Psuedo-Aristotle's

[50] Laird (1986, pp. 44-5); Murdoch and Sylla (1978); Clagett (1959b).

[51] Cf. Clagett & Moody (1952: pp. 213-9).

[52] Clagget (1978). See also Laird (1991) and Simms (1987).

[53] Clagget (1978). vol. iii. p. 1225.

mechanics.[54] His works included mathematical analyses of machines, in terms of mathematical mechanics, which were reduced, primarily, to the elements of force, impact, weight, and motion. This analysis integrated geometry and mechanical arts – an integration of Archimedean theories of geometrical mechanics with fifteenth century technological practices – and postulated that the principles of mechanics and the principles of Nature had an analogous explanatory connection. Leonado was akin to Roger Bacon and regarded those who did not read Nature "by the light of experience" with contempt. However, unlike Bacon, he regarded "experience" not in terms of mystical insight, nor just observation, but in terms of an interventional exploration of "the processes of Nature" through chemistry, mechanics, and dissection. These "processes" were treated in his experiments, models, and art, as mechanisms. Leonardo's writings suggest that he was formulating the precepts of mechanical realism in his studies of Nature and mechanics. It is in the work of Leonado da Vinci, inspired by his readings of Archimedes, with his interest in Nature, proficiency in mathematics and mechanics, that reveals a trace of the emergence of mechanical realism prior to the "scientific revolution".[55] However, Leonardo's approach of exploring natural phenomena in terms of "natural mechanisms" experimentally, applying geometry to solve problems in natural philosophy, was a continuation of medieval efforts in these directions rather than a radical or novel break from them. This approach was characteristic of both Medieval and Renaissance natural philosophers and mathematical practitioners.

Archimedes' fame as an inventor of fantastic machines was widespread in the fifteenth century, largely through the account of Plutarch's *Life of Marcellus*.[56] It is ironical that it is in this text that Archimedes is claimed to have destroyed all his designs for machines because of the ignobility and

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[54] Clagget (1978, p.490-1). See also Simms (1988) for a description of Leonardo's design of the *Architronito* (a steam cannon) based upon the drawings of cannon in *De Re Militari* by Valturius, who stated that the cannon had been invented by Archimedes. There is a lack of any supporting evidence for this claim. A physicist, Ioannis Sakas, used Leonardo's sketches to build this device in the mid-1980s. Simms reported that it projected a missile (a 10 oz. tennis ball filled with hardened cement) to a distance of 150 to 200 ft. within seconds. See Galluzi (1987, pp.91-5) for a discussion of Leonardo's use of Aristotelian notions of motion (as presented in Pseudo-Aristotle's *Mechanica*) and the Archimedean principles of geometrical mechanics. See Kemp (1981) for a discussion of Leonardo's designs for machines and devices (including hydraulic devices, fortifications, weaponry, flying machines, submarines, the parachute, and the helicopter.)

[55] Dampier (1938: pp. 32-3) argued that modern science would have begun with Leonardo da Vinci if he had published his work. Hart (1961: pp. 347-8) noted that the works and notebooks of Leonardo da Vinci, after his death, were primarily of interest to sixteenth century wealthy collectors and patrons of art. He claimed that there is little evidence of any specific attempts to recover his notebooks for the sake of their scientific content.

[56] Plutarch, 1961, *Lives*, Perrin (trans.), Cambridge: Harvard University Press.

danger of such records.[57] Although famous for his mechanical inventions there are no surviving texts, directly attributed to Archimedes, which contain his reputed devices; only second and third-hand accounts remain. His surviving works include the geometrical solutions to the sphere and cylinder, conoids and spheroids, the equilibrium of planes, spirals, buoyancy, quadrature of the parabola, the diameter of the Earth, numbers, square roots, irrational numbers, arithmetic, a method of integral calculus, the diameter of the Universe, probablity, solids, centre of gravity, and measurements.[58] There are references to lost works on polyhedra, numbers, balances and levers, gravity, optics, the mechanical motions of heavenly bodies, parallel lines, circles, triangles, and machines. His only remaining description of a mechanical device is his orrey to model the mechanical motion of the heavens. In the *Method* (addressed to Eratostheses) Archimedes described "a certain method, by which it is possible for you to get a start to enable you to investigate some of the problems in mathematics by means of mechanics" and wrote "for certain things first became clear to me by a mechanical method, although they had to be demonstrated by geometry afterwards because their investigation by the said method did not furnish an actual demonstration."[59] It is this mechanical method that had wide appeal to the Medieval and Renaissance mechanists and mathematicians.[60]

It is beyond doubt that the works of Archimedes had a profound influence on Galileo. This profound influence can be read from Galileo's own words: "I cover myself with the protecting wings of the superhuman Archimedes, whose name I never mention without a feeling of awe."[61] In 1586 Galileo constructed a hydrostatic balance, following Archimedes' geometrical arguments, to determine accurately the relative amounts of two metals in an alloy mixture, which he described (in Italian) in a paper published in 1644.[62] In the same year, 1586, Galileo also studied the Archimedean concept of "the centre of gravity", and wrote a paper (in Latin) on "Theorems about the Centre of Gravity in Solids".[63] Galileo wrote *On Motion (Du Motu)* applying Archimedes' principle of motion in a medium whilst retaining Aristotle's notion of natural places and the medieval notion of impetus in 1590-1.[64] He argued that a falling body should be treated as a body rising, falling, or floating in a medium and,

[57] Plutarch xviii, pp. 4-5. Cf. Authier (1995) and Latour (1990) for discussions of the narrative construction and use of Plutarch's legend of Archimedes.

[58] c.f. Heath (ed.) *The Works of Archimedes with the Method of Archimedes* (N.Y.: Dover, n.d.).

[59] *Ibid.* p.13 of the supplement *The Method of Archimedes.* According to Heath, Heiberg discovered this work by Archimedes in 1906. The MS was written in Greek, on tenth century parchment, and the final leaves were written on sixteenth century paper.

[60] See Keller (1971) for a description of how salvage operations in Venice put Archimedes' principles into practice during the sixteenth century.

[61] Galileo *On Motion and On Mechanics* (trans. Drabkin & Drake, 1960) p. 67

[62] A translated version of this paper, "The Little Balance", can be found in Fermi & Benadini (1961).

[63] This paper was not published until 1638 as an appendix to the *Two New Sciences* (trans. Crew & de Salvio, 1914).

[64] This was unpublished until 1883.

consequently, it could be treated in Archimedean terms as a body "reduced to weights of a balance."[65] He wrote *On Mechanics (Le Meccaniche)* in 1593-4 giving Archimedean geometrical treatments of the simple machines: the wheel and axle, the wedge, the balance, the lever, the inclined plane, and the screw.[66] He started from his premise that all simple machines could be reduced to a problem of an Archimedean balance. This argument was based on the Archimedean principle that all machines operate on the same physical principles so a complete understanding of any one of them is adequate for the deduction of the mechanical properties of all the others. Having chosen the balance as fundamental and used it to derive the laws for an inclined plane, the lever, the windlass, the capstan, the pulley, and the screw, Galileo constructed a 'dynamic equilibrium' method as the basis of his physics. He used this method in his treatment of hydrostatic phenomena in *Discourse on Floating Bodies* (1612) and in his *Dialogue on the Two Chief World* Systems (1632). He used this method to describe motion as separated into two independent horizontal and vertical axes to describe the fall of a body from a moving point as that of a parabola. He *rhetorically* argued that the Earth could revolve around the Sun (without the breath being snatched from our mouths nor birds being flung from out of the sky). In his last work, *Two New Sciences* (1638), he concentrated on explaining natural motion using the inclined plane.[67] This involved using the pendulum experiment and the balance as exemplars for the description of all natural motion.

According to Seegler (1966, p.4), Galileo probably first became acquainted with the works of Archimedes in 1583 through the Tuscan court tutor, Ostilio Ricci, a pupil of Nicolò Tartaglia (1500-57), who, in 1543, had translated the works of Archimedes into Latin. Tartaglia taught perspective, architecture, and in 1537 published his mathematical science of ballistics.[68] He also taught mathematics, surveyed land, designed fortifications, made maps, and invented mathematical instruments. His studies included arithmetic, geometry, music, astronomy, perspective, and architecture. He had translated Euclid's works into Italian in 1543. In 1551 he published his Italian translation of Archimedes' *On Floating Bodies* and, using Archimedes' hydrostatics, Tartaglia derived and proposed a method of re-floating wrecks.[69] He had also studied and translated into Italian Pseudo-Aristotle's *Mechanica* and declared that mechanics based on the principles of weight was "the cause of

[65] Galileo (1960) p.38. In this work he presented his "physical analogy" of the balance for naturally moving bodies and for the motion of a body on an inclined plane and pendula.

[66] Published in French in 1634 and in Italian in 1649.

[67] See Naylor (1989) and Cantor (1989) for discussions of Galileo's rhetorical use of his "experiments". Both Naylor and Cantor argued that Galileo anticipated the results of his experiments and question whether those "experiments" had ever been performed at all.

[68] Keller (1975: p.19). Tartaglia's famous books are *Nova scienta* (1537) and *Questi et inventioni diverse* (1546). Parts of *Questi* Bk.VII and all of Bk.VIII are translated and reproduced in Drake and Drabkin (1969: pp. 104-43).

[69] Laird (1986, p.52), Clagget (1978, pp.508-607). In his book *Travagliata Invenione*, there is a translation and commentary on Archimedes' *On Floating Bodies* BK.I. Cf. Keller (1975, p.21).

every ingenious mechanical invention".[70] He argued that arguments about Nature could only be based on experience whereas abstract arguments about mechanics should be based on mathematics. This lead him to assert that arguments based on mechanics were superior to those based on mere observation because reasoning based on mathematics was more rigorous than reasoning based on experience. When observation and mechanics did not agree then the notions of "error" or "material hindrances" could be used to explain the discrepancy.[71] By adopting this tactic Tartaglia had pre-empted the seventeenth century method of transdiction.[72] It was this method that was central to the use of mechanics as an explanatory tactic. The discrepancies between the fall of a body and a parabola, for example, could be transdicted as the mechanical consequence of the invisible force of friction. A subsequent mechanical experiment could be constructed to demonstrate friction and, due to the presumed universality of such a demonstration, it could be taken to have disclosed the reason for the initial failure of mathematical description to match experience. Tartaglia accepted the Aristotelian classification of mechanics as an "subalternated science" because its method was abstract mathematical demonstration but its subject was physical and consequently both mathematics and experience were required in the development of mechanics. He argued that mechanics provides knowledge of how to calculate the strength (*virtù*) and power (*potentia*) of any machine to augment the strength and power of men by any degree.[73] According to Laird (1986, p.53), Tartaglia attempted to inscribe a formal mathematical treatment of mechanics by combining the statics of Archimedes with the dynamics and kinematics of Psuedo-Aristotle but was unsuccessful because he could not combine the Archimedean proofs based on equilibrium and the Aristotelian arguments based on velocities. However, Tartaglia had laid down the challenge to his sixteenth century Italian contemporaries.

Laird claimed (1986, p.54) that Francesco Maurolico was the first of Tartaglia's contemporaries to take up this challenge. He already had established his reputation in astronomy, optics, and by translating and commenting on the works of Euclid, Archimedes and Pseudo-Aristotle. In *Problemata mechanica cum appendice* he discussed the scope and classification of mechanics within the sciences.[74] He listed mechanics (along with music, astronomy, perspective, geography, architecture, painting, sculpture, stereometry, and cosmography) as an intermediate science between the mathematical and the physical that was distinct from the secular arts. He considered mechanics to be a

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[70] *Questi*. Bk. VII. Keller (1975, p.20). For discussions of the Psuedo-Aristotelian basis of Tartaglia's mechanics see Laird (1986, pp.52-3) and Wallace (1984, pp. 203-5).

[71] *Questii*, fols., 78r-v, quoted and translated in Drake and Drabkin (1969, pp.105-7)

[72] Osler (1994, p.117), following Mandelbaum (1964), termed this as the methodological problem of *transdiction*. This is a form of inference by which an explanation is constructed in terms of an, as of yet, unobserved mechanism in order to explain the deviation of an observation from theoretical expectations.

[73] *Questii*, fol., 82v, Drake and Drabkin (1969, p.111)

[74] This book was published in 1613 well after Maurolico's death in 1575. The preface to this book and several of the problems can be found in Clagett (1978, pp.784-7).

part of "contemplative philosophy" due to its mathematical part. He argued that the dynamics and kinematics of Pseudo-Aristotle's mechanics had to be based on "the doctrine of equal static moments" and consequently mechanics had to be based on Archimedean principles. It is this notion of the primacy of Archimedean statics that was shared by many subsequent sixteenth century Italian mechanists.[75] Guidobaldo used Archimedean techniques, in *On the Equilibrium of Planes*, as exemplars to solve the problems set by Psuedo-Aristotle starting from the lever and then on to the rest of the six simple machines (the lever, the wheel and axle, the inclined plane, the wedge, the screw, the balance).[76] Guidobaldo aimed to establish mechanics as a branch of rigorous axiomatic geometry and claimed that any machine based on such a mechanics would work in the real world. Another sixteenth century Italian military engineer called Giulio Savorgan, also inspired by Archimedes, innovated Italian town fortifications, developed mechanics and invented 'Archimedean instruments' to aid the lifting and transportation of heavy cannons.[77] He invented light, robust, and powerful lifting-gear based on spur-gears, worm-gears, rack-and-pinion, block-and-tackle, winch and pulley, screw-jacks and ratchet-jacks. Bernardino Baldi considered mechanics to be a "subalternated science" due to its physical subject matter described in terms of geometrical proofs. In his view, mechanics was consequently of an equal status to optics, music, and astronomy. In his treatment of mechanics he followed Maurolico and argued that the solutions to the problems raised by Pseudo-Aristotle should be based on Archimedean proofs. However, he argued that mechanics should not be based purely on static principles but must also be based on motion, power, and impetus.[78]

The Aristotelian and mathematical science of mechanics was established in Italy through the influence of the university at Padua.[79] Since the fourteenth century Padua had been a centre for mathematical subjects (including astronomy, astrology, geometry, optics, and geography) and was the first Italian university in the sixteenth century to offer lectures in mechanics from the chair of mathematics. According to Laird (1986, p.48), mechanics was first introduced into the university ciriculum at Padua in the 1560s in the form of lectures on Pseudo-Aristotle's work. The elevation of mechanics from the banausic to the academic was established through the influence of mathematically educated Aristotelian scholars such as Niccolò Lenico Tomeo and Alessandro Piccolomini.[80]

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[75] Cf. Laird (1986, p. 55)

[76] Guidobaldo was an aristocrat and a military engineer. Guidobaldo's famous books are *Le mechaniche* 1581, see Drake and Drabkin (1966, pp.239-328), and *Liber mechanicorium*, published in Latin 1577 and Italian 1588, see Wallace (1984, p.206). These books described the simple machines as described by Heron. Federico Commandino translated Heron's works into Latin in 1573. Heron reduced the problem of the mathematical description of the six simple machines to the properties of the circle. His treatment implicitly utilised a principle of moment. Cf. Laird (1986, p.55).

[77] Keller (1975, pp. 21-32.)

[78] Cf. Laird (1986, p.56-7) and Rose (1975, pp.248-51).

[79] Cf. Schmitt (1976: pp. 35-56).

[80] Tomeo was a professor of philosophy at Padua from 1497 to 1509. Cf. Laird (1986: pp. 48-9); Rose

Guidobaldo studied there in 1564 and Baldi from 1573 to 1575.[81] Pietro Catena was the first lecturer in mechanics at Padua and gave lectures between 1564-1573.[82] His successor was Guiseppe Moletti.[83] Moletti classified mechanics as "contemplative philosophy" of mathematical principles of statics, dynamics, and kinematics. According to Moletti, the task of mechanics was to demonstrate the most efficient means of performing the maximum amount of work with the minimum of effort. For Moletti, mechanics was a science and not an art because the geometrical first principles of mechanics were "necessary and eternal" whereas the arts were contingent upon human ends. The end of science was the knowledge of causes and truth whereas the end of arts was productive work. He argued that the first principles of mechanics were natural means, that mechanics was to be found in all the works of Nature, and the first principles were "Natural Laws". Moletti transformed the traditional classification of mechanics as a "subalternate science"; whilst he still considered it to be "intermediate" between the geometrical and the physical it was based on both mathematical and natural truths.[84] Moletti formally reclassified the subject of mechanics to be that of natural principles. In the work of Moletti, mechanics was presented as a natural science. By declaring that the science of mechanics was based on "Natural Laws", Moletti had paved the way for Galileo's mechanical realist physics.

A similar view can be found in the writings of Francis Bacon. In *The New Organon* he was critical of sixteenth century arts, intellectual sciences, and philosophy. [85] He considered Greek science to be childish, due to their basis on "bland and specious generalities" that lead only to "disputes and scrappy controversies" and "almost stopped in their tracks", and praised the mechanical arts for progressing.[86] He proposed

"the production of a Natural History by making a history not only of Nature free and unconstrained (when nature goes its own way *and does its own work*), such as a history of the bodies of heaven and

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and Drake (1971: p.79). He translated Pseudo-Aristotle into Latin and published a commentary in 1525. Piccolomini taught moral philosophy at Padua in 1539. Cf. Laird (1986: p. 49); Rose and Drake (1971: p. 82). On his scientific work cf. Suter (1969).

[81] Cf. Laird (1986, p.59)

[82] *Op cit.* pp.59-60; Rose and Drake (1971: p. 93). Catena was professor of mathematics from 1547 to 1576.

[83] *ibid.* pp.60-2. Moletti was professor of mathematics at Padua between 1577 and 1588.

[84] Moletti's arguments can be found in *In librium mechanicorum Aristotelis expositio tumultaria et ex tempore*. Milan, Biblioteca Ambrosiana MS. S 100. I have relied on Laird's commentary, translation, and selections.

[85] Published in 1620. Quotations and references taken from the Jardine and Silverthorn edition (2000).

[86] *New Organon*, pp. 6-7. Bacon did not give any examples of the arts, intellectual sciences, philosophy, or childish Greek sciences to which he referred. He only gave a single reference to Plato's reference to Atlantis in *Timaeus* (24D ff.) and the description of Scylla in Ovid (*Metamorphoses*, x.III. 732-3).

the sky, of land and sea, of minerals, plants and animals; but much more of *nature constrained and harassed* when it is forced from its own condition *by art and human agency, and pressured and moulded.* And therefore we give a full description of all the experiments of the applied part of the liberal arts, and all the experiments of several practical arts which have not yet formed a specific art of their own." (2000, pp.20-1, my italics.)

He argued (2000, pp.69-70) that the mechanical arts were founded on natural axioms induced from experience and were capable of growth and flourishing provided that they were directed according to utility. He praised the mechanical arts for providing a "variety of objects and splendid equipment", having "contributed to human civilisation", and being based on "axioms of nature" discovered by observation and subtle, patient, ordered movement of hands and tools. He cited the clock as an example of "a subtle and precise thing that seems to imitate the celestial bodies in its wheels, and the heartbeat of animals in its constant, ordered motion; and yet it depends on just one or two axioms of nature." He considered (2000, p.100) the Arts to be praiseworthy as the source of civilisation and political advantage in general and the discovery of the art of printing, gunpowder, and the nautical compass in particular. The mechanical arts were the noblest human pursuit and "right reason and sound religion would govern its use."

However, Bacon (2000, pp.53-5) was critical of natural philosophies that reduced Nature to mechanisms because mechanics was based on only "a few axioms of Nature" and measurement was insufficient to reveal "the ultimate causes of Nature". Bacon was not a reductive mechanical realist because he considered mechanics, although based on a few "axioms of Nature", to be artificial and that Nature, when left to its own ways, was not mechanical. Bacon's mechanical realism was a *modest* mechanical realism in as much as he considered the fundamental principles of mechanics to be natural principles but he did not consider all natural principles to be mechanical. Furthermore, he considered (2000, p.109) mechanics to be subordinate to physics because the latter, through observation of Nature going its own way, could discover latent processes, efficient and material causes, and latent structures, that occur through the common and ordinary course of Nature. In many respects, Bacon maintained an Aristotelian physics. Experimentation, in the form of interventional material practices, could only provide us with a limited kind of knowledge. As Bacon put it (2000, p.33): "All man can do to achieve results is to bring natural bodies together and take them apart; Nature does the rest internally."[87]

Another proponent of this interpretation of machine performances at the turn of the seventeenth century was Giovanni di Guevara.[88] Guevara analysed mechanics using both Archimedean

[87] Note that the word "results" is a translation of the Latin *opera.* This word has a variety of meanings. It can be taken to mean "results", "effects", and "work". It is derivative from *operatio*, which is translated as "operation" or "practice".

[88] Cf. Laird (1986) pp. 65-7 and Wallace (1984) pp. 208-16. Guevara was a Spanish noble from Naples, *praepositus generalis* of the Clerics Regular Minor, the Bishop of Teano in 1627, and a papal legate to Philip IV of Spain. His *In Aristotelis Mechanicas commentarii* was published in Rome in 1627.

principles and Pseudo-Aristotelian mechanics. He dealt with the principles of mechanics, centres of gravity, the simple machines, Psuedo-Aristotle's thirty-five mechanical problems, the scope of mechanics, and its relation with the other sciences. He defined mechanics as the art or science of applying geometrical principles to heavy and light things that must be moved or brought to rest artificially. Mechanics was based on the weight of the moved body and the strength of the mover (which could be an impetus or a machine) and it consisted in discovering the appropriate powers needed to move loads and to *supplement* Nature. He distinguished two subjects of mechanics: (i) its material subject; and, (ii) its formal subject. The material subject of mechanics was defined in terms of the quantity of weight of a body and the powers required for it to move or stop. The formal subject was defined as the mathematical treatment of the material subject. Guevara's formal treatment of mechanics was in terms of marvellous and artificial motion and rest (each, in turn, was treated in the Aristotelian terms of violent and natural motion and rest).[89] These distinctions allowed Guevara to describe how mechanics and natural philosophy dealt with the same subject differently. Guevara argued that natural philosophy was concerned with marvellous motions and rest whereas mechanics was concerned with artificial motions and rest; both natural philosophy and mechanics could analyse their distinct kinds of motion and rest in terms of natural and violent motion. He argued that natural motion was apparent in any motion that was produced by machines. Although a machine operated upon violent motions, from an external source, the behaviour of that motion could be analysed in terms of natural motions. In the operation of any machine there were both violent and natural motions at work. In other words, human intervention was required to produce and activate any machine but once that machine had been produced and activated then Nature played its part in how that machine operated.[90] Consequently, the operation of mechanical devices was based on both human interventions and natural principles.

In 1592 Galileo Galilei succeeded Moletti as professor of mathematics a Padua. He was trained as an artisan and an engineer rather than a philosopher or mathematician.[91] As Seegler pointed out (1966, p.7), Galileo's natural philosophy was that all conclusions had to be checked "directly with nature to ascertain if they agreed with actual observations". However, the key to understanding his

[89] In the Aristotelian terms, violent motion arose from an external source whereas natural motion arose from the body in question.

[90] A similar view of material practices is given by Gooding (1990) and Hacking (1983). I have also heard experimental physicists talk in similar ways about the participation of Nature in their work. It seems that many experimentalists are all too aware of the artificiality of the experimental apparatus, they accept that human intervention has a fundamental role in an experiment, but claim that the object of their investigation is how Nature responds to their interventions. I shall discuss this further in chapter six.

[91] Cf. Drake (1957), Seegler (1966), Settle (1967), Shea (1972), and Redondi (1987), for biographies of Galileo's life and works. Also see Bedini (1994, pp.89-95) and McMullin (1967, pp.256-92) for discussions of Galileo's close relationship with mechanicians, instrument makers, and craftsmen of Venice, Padua, and Florence.

"natural" philosophy is to understand the "Nature" that his conclusions were to be checked against. For Galileo, following Moletti, Nature was both a source and a resource for physical theories. However, geometrical methods did not allow any investigation into quality. It is for this reason that the notion of quality, as an object of natural philosophy, was discarded, demarked as subjective, and removed from "the realm of Nature". It was a direct consequence of this reduction that mere experience did not qualify as a legitimate source of knowledge. Checking directly with Nature involved an intellectual *a priori* knowledge of mathematics as being the only means of apprehending the truth of what was being experienced. Physics became *a priori* science in the hands of Galileo – and by Descartes later – *and consequently the Euclidean-Archimedean geometry became the necessary language to understand Nature.* He argued that the efficient causes of mechanics were the necessary causes and fundamental mechanisms of Nature. Galileo was not an empiricist and experience had to be mathematical in order to qualify as an observation. Experience had to be described in the form of Euclidean-Archimedean geometry if one was to read "the book of Nature". Galileo was able to develop the Archimedean statics into the dynamics of the new physics that aimed to describe everything in terms of number, figure, motion, and *causal mechanism.* He did this by disregarding the primacy of perception and affirming the technical exemplars of Euclidean geometry, inscribing motion solely in terms of the translation of a body from one geometrical point to another. For Galileo, mechanical realism was implicit to his scientific method. The natural philosopher to understand the true cause of natural phenomena s/he must be able to replicate or reproduce the natural phenomena by constructing an artificial device.[92] It was this move that was essential for the development of Galileo's new physics and was to provide the template for all subsequent physics. The mathematical motions that were to be projected upon the natural phenomena were the motions of the six simple machines. Circular motion and the coupling of anti-parallel linear motions could be described in terms of the geometrical solution to the wheel (and consequently the pulley). Orthogonal changes in motion, the transference between horizontal motion and vertical motion, could be described in terms of the geometrical solution to the wedge (the transference between vertical and horizontal described in terms of the inclined plane). Transference between circular motion and motions orthogonal to the plane of the circle could be described in terms of the screw. Galileo had reduced all these machines to the operation of the lever and then the balance.[93] This provided him with a complete set of uniform mechanical motions, with which to mathematically project on to all natural movements, and be reduced to a single unitary mechanical motion. It was the balance that, as a metaphor and a model, that was to become central to all physical

[92] Galileo *On Motion and Mechanics*, p.421.

[93] In *Two New Sciences* (p.124) Galileo defined his notion of force (*forza*) in terms of the lever as "mechanical advantage". He also, after making reference to Archimedes' treatment of *Equilibrium* (cf. Heath *The Works of Archimedes* pp. 189-220), proposed the derivation of "most other mechanical devices" in terms of "the Law of the Lever" (*TNS* p.110-2).

explanation and law.[94] The laws of conservation (mass, charge, energy), Newton's Laws of Motion, the First Law of Thermodynamics, and the applicability of mathematical equations to natural processes, were all premised upon the metaphor of the balance as a fundamental mechanical principle of Nature. Furthermore, by utilising the method of transdiction whenever the mathematical projection of the balance failed to match experience, the projected invisible counter-mechanisms used to correct the discrepancy could themselves be projected as balances.[95] Each natural process could be described in terms of the interaction between balances and balances within balances. Any external force could itself be simply described by mathematically projecting the lever. The mathematical projection of balances and levers made the mechanical world-view and the idea of the clockwork universe possible. All that was required to solve the problem of transdiction was to devise a further experiment to show the mechanical action of the correcting mechanism. This could then be mathematically projected over the original phenomenon. This projection embodied the precepts of mechanical realism and made the experimental use of mechanical devices to ascertain the fundamental mechanisms of Nature possible.

Galileo made essential two contributions to mechanics that made modern experimental physics possible. The first contribution was technical. Galileo innovated geometrical techniques to reduce all motion to a single unitary mechanical motion: the motion of the balance. As a consequence of this innovation he was able to inscribe simple time-reversible mechanisms, such as pendula, in terms of Euclidean-Archimedean geometry and provide a mechanical determination of time. The second was metaphysical. He was able to establish his mechanical realism as a basis for using mechanical devices, experimental apparatus, *rhetorically* to "discover" mechanical principles of Nature. Galileo went further than had any of his Paduan predecessors. Not only were the motions of simple mechanical devices treated as natural, as Moletti had proposed, but they were also to be used to determine the mathematical "Laws of Nature". It was the geometrical treatments of simple mechanisms that were to be classified as "the Laws of Nature" and all natural movements were to be treated as simple mechanisms. Galileo's reductive mechanical realism was both the precursor to the "mechanical world view" of the seventeenth century mechanical philosophers and also provided a method to investigate Nature mechanically.

The development of mechanics *as both a mathematical and a natural science* could only be described as platonic in terms of a conflation of platonic uses of *techne* and *episteme*. The causal *logos* of the (platonic) *techne* of mathematical mechanics was presented as the unchanging and eternal *episteme* of Nature. Thus, from its onset, mathematical physics was an epistemic *logos* of *techne*; it was *techne*-logical. This move was facilitated by the ambiguity between mathematical reasoning as *techne*

[94] Machammer (1998) argued that Galileo should be situated in the Archimedean heritage and that the mathematical treatment of the balance was central to Galileo's physics.

[95] An example of this in Galileo's work is the solution to the discrepancy of the motion of a body from the mathematically projected quadrature of a parabola. (Cf. *Two New Sciences* pp. 252-6). Galileo explained this discrepancy in terms of air resistance. This transdiction was demonstrated by the dropping of two cannon balls and the pendulum thought experiments.

and *episteme* within the texts of both Aristotle and Plato, but it was also novel. This novelty allowed both the reification of the products of Euclidean-Archimedean geometry and the transformation of the status of the mechanical arts to mechanical science to become a means of writing the book of Nature. However, this transformation occurred within the context of the European desire for novel technological powers. It is this desire that provided the condition for naturalness of the conceptual synthesis of the precepts of mechanical realism and the possibility of both mathematical natural science and modern scientific technology. Once this metaphysical foundation was secured then the *episteme* of Euclidean-Archimedean geometry was foregrounded and the *techne* was backgrounded. The technical acts of writing the book of Nature could be ignored (as mere means) and it could be read as if written by God. The history of the dissemination of Euclidean-Archimedean geometry is one of the presentations of its practice as the discovery of truths. This remained the case in European mathematics until the nineteenth and twentieth centuries' construction of non-Euclidean geometries. It was Euclidean-Aristotelian-Archimedean science of mechanics that provided the template for the mathematical projection of the lever and the balance as the blue print for the physics of the seventeenth century. Once the precepts of mechanical realism had been embodied in mathematical projection then both modern experimental physics and modern technology became conceptually possible and linked by a technique.

CHAPTER THREE:

THE "MAKING" OF THE GROUND-PLAN OF NATURE:

"[T]here are absolutely no judgements in Mechanics which do not also pertain to Physics, of which Mechanics is a part or type: and it is as natural for a clock, composed of wheels of a certain kind, to indicate the hours, as for a tree, grown from a certain kind of seed, to produce a certain kind of fruit. Accordingly, just as when those who are accustomed to considering automata know the use of some machine and see some of its parts, they easily conjecture from this how the other parts which they do not see are made: so, from the perceptible effects and parts of natural bodies, I have attempted to investigate the nature of their causes and of their imperceptible parts."
(Rene Descartes, *Principles of Philosophy*, p. 285)

"Nothing is more dangerous for a theologian than to know the *Elements* of Euclid."
Pierre Gassendi (*Disquisitio metaphysica*)

Mechanical Realism and The Mechanical World-View:

In order to reveal the root of modern metaphysics, Heidegger began an analysis of Descartes. The usual interpretation of Descartes' *cogito sum* is that of the thinking-being as "I", as the human subject, as the self-declared centre of thought that placed doubting at the beginning of philosophy in order to provide reflection upon knowledge itself and its possibility, placing epistemology prior to ontology. For Heidegger (1999b, p.298), this was a story that "at best [is] only a bad novel" because it neglected the questioning of substance that was central to Descartes' philosophical enterprise in the *Meditationes de prima philosophia* (1641). Heidegger criticised the usual interpretation that Descartes' philosophical project was a form of scepticism, subjectivism, or egoism. Heidegger placed Descartes within the context of an historical period in which a new assault upon reality had been embarked upon. Descartes' enterprise reflected the passion for this new assault and an inquiry to bring clarification to the essence of the new enterprise. In Descartes' work, it is the mathematical itself that is the centre, and his philosophical efforts were directed towards grounding the mathematical in terms of its won inner requirements by explicating it as the standard of all thought and establishing its rules. Descartes' self-appointed task was a work of reflection upon the fundamental meaning of the mathematical. This reflection was concerned with the totality of beings and the knowledge of that totality, and, therefore, was a reflection upon metaphysics. Heidegger referred to *Regulae ad directionem ingenii*, a posthumously published unfinished work by Descartes, in his discussion of Descartes' mathematical and metaphysical work.[1] In this work, Descartes emphasised that clear and insightful intuition, or certain deductions, are the routes to knowledge. He also argued that method is necessary for us

[1] For an English translation of this text see Rene Descartes, *Rules for the Direction of the Mind*, Lafleur translation, Indianapolis: Library of the Liberal Arts, 1961.

to have truths at all. This method was to consist in the order and arrangement upon that which "the sharp vision of the mind" is to be directed if truth is to be discovered. If mathematics, in the sense of *mathesis universalis*, was to ground and form the whole of knowledge, then special axioms were required. These axioms needed to be intuitively self-evident and establish in advance what constitutes being and from where, and how, the essence of being is to be determined. The basic mathematical projection had to be based upon its own ground, as a basic principle, and be indubitable. Descartes did not start his discourse with doubt because he was a sceptic, but in order to clear the way for the mathematical as posited as the absolute ground and foundation. Hence Descartes' *cogito* was something mathematical when in thinking itself it takes cognisance of itself as something we realise for ourselves as something we already have. As Heidegger argued (p.302), Descartes' formula, *cogito ergo sum*, was not an inference because the *sum* was not the consequence of thinking, it was the *fundamentum*. Descartes' project was founded upon the "I posit" proposition because it allowed his work to be presented as something independent from that which is given before hand and as that which already lies within. The mathematical "I" was presented as the special subject, against which all remaining things first present themselves as what they are, that mathematically provided the fundamental relation from which all things receive their thingness. In relation to the "subject" things could then stand as something else, as *objectum*, and became "objects".

Descartes established a mechanical philosophy of Nature upon the foundation that all natural phenomena could be explained in terms of innate matter and motion in geometrical space. He argued that the Universe is a plenum and that the matter filling it is infinitely divisible, identical with geometrical space, and has only the property of extension. He argued that extension could be understood in terms of *a prior* knowledge, there is no need for any appeal to experience or observation, and consequently, the first principles of natural philosophy could be known *a priori* and lead to the discovery of essences. Experiences and observations were only required to determine the contingent actuality of phenomena. Descartes was committed to the Galilean mechanical physics and mechanical philosophy. His 1641 *Meditationes de prima philosophia* contained his demonstrations of the metaphysical foundations of the epistemological basis of his mechanical philosophy. His aim was to provide metaphysical foundations for the epistemology of mechanical philosophy that would replace the Aristotelian natural philosophy without appealing to an alternative ancient philosophy.[2] His method was to use sceptical arguments instrumentally in order to clear the way for his arguments in favour for mathematics as a foundation of indubitably certain and demonstrative knowledge. Furthermore, he also used arguments for God choosing to be bound by the necessity that God had freely created in the physical world and consequently the *a priori* arguments for the eternality, universality, and necessity of mathematical first principles were the metaphysical basis of his epistemology of physics.[3] Furthermore, his points of departure were continuous with the theorlogical presuppositions of Medieval theology because his metaphysical arguments about God's creation of eternal,

[2] See Osler (1994, ch.5) and Shea (1991) for further discussions of this point.

[3] See Bréhier (1968), Curley (1984), Hatfield (1989), and Garber (1992) for further discussions and arguments.

necessary, and universal truths was tempered by, and drawn from, the Medieval traditional discussions about the absolute and ordained powers of God.[4] The theological tradition played a formative role in the development and interpretation of Descartes' natural mechanical philosophy. Furthermore, as discussed in the last chapter, philosophical discourses for the eternal necessity of mathematical truths occurred throughout the Medieval. Descartes, Galileo, and Kepler identified mathematical truths as eternal truths that were central to the natural order of the physical world and all shared a concern with the relationship between God and mathematical truths.[5] Descartes' arguments for God's creation of mathematical truths provided the metaphysical foundation of his epistemology because if certain fundamental mathematical truths are necessarily true then we could have *a prior* knowledge of them. These *a priori* indubitable truths provided Descartes with a foundation for his deductive methodology. From this "standard of certainty", Descartes was able to provide arguments in the *Discourse on Method* for his method of systematic doubting, the *cogito*, the existence of God, the existence of the soul, and the essence of matter. He was able to instrumentally start from his conception of the *cogito* based on the components of doubting, thinking, and being, to argue the *cogito* was indubitable as a transferable standard by which the reliability of any knowledge claim could be made. In the *Discourse on Method* (p.54) this standard provided "a general rule that the things we conceive very clearly and very distinctly are all true, but that there is nevertheless some difficulty in being able to recognise for certain which are the things we see distinctly." It was this general rule that Descartes used to argue that if this general rule were true, and it must be, then there is a necessary connection between that which is clear and distinct in our minds and the natural order of the physical world created by God. If the rule were false the God would be a deceiver and this would be in contradiction with the conception of God in terms of perfection. Given that mathematical truths are clear and distinct then they must provide truths of the physical world. Descartes used this reasoning to establish his characterisation of matter in terms of geometrical extension, infinite divisibility, and primary and secondary qualities. These characterisations constituted the fundamental elements of the physical world within Descartes' natural philosophy.

On the basis of these elements, Descartes asserted laws of Nature as the first principles of his natural philosophy. These laws were given in the *Principia philosophiae* (1644) to be: (1) God was the first cause of motion and He always conserved an equal quantity of it in the Universe; (2) the principle of inertia; (3) the fundamental law of impact. Descartes appealed to the perfection of God in order to justify these laws of Nature and consequently *a priori* knowledge of Nature and, given that the existence and content of these laws are derived from God's attributes, required knowledge of God's attributes. As a consequence of the perfection of God, the same laws of Nature would govern any world created by God, and therefore in order to obtain knowledge of this particular world more than just the *a priori* laws of Nature are required. For Descartes, knowledge of the laws of Nature was necessary but not sufficient to

[4] Osler (1994, ch.1 and 5), Garber (1992, pp. 148-55), Rubidge (1990, pp.27-9), and Funkenstein (1986, pp. 179-92).

[5] See Osler (1994, p.127) for further discussion of this point.

explain particular phenomena. Observation and experiment were also needed to explain the phenomena of Nature we needed both to know which possible phenomena are actually existent in this world, and which of the several possible mechanisms, compatible with the same general law, were involved in the production of the phenomena in question. Even though the laws of Nature were eternal and necessary, the actuality of the phenomenal world was contingent because the particular implementation of the laws of Nature was contingent.[6] To know which mechanisms God had used to make the phenomenon in question, as well as which phenomena God had made, one needed to observe and experiment. In Descartes' discourse, the actual was the made and God was the maker. The laws of Nature present the possibilities of God's choices when making. In terms of the possibility of human knowledge, observation and experiment were constrained in terms of what could be made or manipulated mechanically either in practice or in thought. Descartes' scientific method was to produce mechanical analogies (or models) that could be derived from first principles and would produce the same phenomena that were observed to exist in the world. Observations and experiments could then be used to eliminate deduced mechanical models from the potentially infinite set and provide criteria by which judgements regarding which mechanisms were the actual mechanisms involved in the production of the phenomenon in question. By using "empirical evidence" to eliminate deduced possibilities, except one, Descartes hoped that the demonstrative character of his natural philosophy would be secured. Experiments and observations were not designed to validate laws of Nature but rather to select from a set of possibilities and to show how the general laws applied to particular phenomena. Descartes' scientific method was to deduce possible mechanisms from *a priori* laws of Nature as proposed explanatory mechanisms that could be eliminated via observation and experiment.[7] Thus Descartes was a mechanical realist due to the fact that he limited explanations of natural phenomena to mechanisms, proposed that a single mechanism (or set of mechanisms) were at work in producing the phenomena, and that machines could be used to determine the truth of any explanation by attempting to produce phenomena *artificially*. The implicit mechanical realism in his philosophy was accompanied by a transformation of the status of craft knowledge from *technai* to *epistemoi*. An understanding of the mathematically rationalised arts, itself transformed into sciences, constituted the basis for an understanding of the productive capabilities of God. Furthermore, for Descartes, once we understood these productive capabilities then we too could become more God-like in our capacity to change and produce things in the

[6] *Principles* pp. xxvi-xxvii and p. 85. See Garber (1978) and Clarke (1982) for further discussion of this point.

[7] The purpose of experiments and observation were not to provide data for the induction of general laws. Rather the general laws were deduced from assumptions regarding the nature of God and logic. These laws were used to deduce the possible explanatory mechanisms. In many respects, Popper and Bhaskar's philosophies of the scientific method owe and great debt to Descartes. They are modern re-workings (de-theologised) versions of Descartes' scientific method, in that the aim of experiment and observation was to deduce explanatory mechanisms from general laws and trying to falsify these by attempting to actualise all the possible explanatory mechanisms until only one was left.

physical world. For example, Descartes wrote,

"we can have useful knowledge by which, cognisant of the force and actions of fire, water, air, the stars, the heavens and all the other bodies which surround us - knowing them as distinctly as we know the various crafts of the artisan - we may be able to apply them in the same fashion to every use to which they are suited, and thus make ourselves masters and possessors of Nature." (*Discourse on Method*, p.78)

Furthermore, by securing epistemological validity to productive success, Descartes was able to secure knowledge of natural principles to productive skills. Hence he argued

"id artisans are unable immediately to execute the invention which is explained in the *Dioptrics* , I do not believe cone can say on that account that it is bad; for, inasmuch as skill and practice are needed to make and to adjust the machines that I have described, so that no detail is overlooked, I would be no less astonished if they succeed at the first attempt than if someone were to learn in one day to play the lute with accomplishment simply because he had been given a good score." (*Discourse on Method*, p.91)

Consequently Descartes' natural philosophy was intimately bound up with the human capacity to make.[8] He was not alone.

In the early seventeenth century an influential group of self-professed mechanical philosophers emerged. These people established a community of writers dedicated to the establishment of the metaphysical foundations of mechanical philosophy, the promotion of the growth of the new mechanical sciences, and the opposition to Aristotelians and the occult. The members of this community included Beekman, Cavendish, Charleton, Descartes, Digby, Gassendi, Hobbes, and Mersenne.[9] These men

[8] Schaffer (1988) made a similar point about Newton's use of similar arguments regarding his prisms. If a prism failed to resolve the seven-coloured spectrum then Newton would argue that it had been made badly. Newton's definition of a good prism was that it showed a seven-coloured spectrum. Collins (1985) also makes a similar point about replication in general to the extent that it is always open to question and controversy whether an experiment has been repeated correctly or not.

[9] For a discussion of Beekman's contribution to the mechanical natural philosophy see Hooykaas (1972) vol. I, p. 566. Beekman did not publish any major works but wrote philosophical letters to his contemporaries. For discussions of Gassendi's contribution see Dijksterhuis (1961), Lennon (1993), and Osler (1994). Gassendi published *Syntagma philosophicum* in 1658. For discussion of Descartes' contribution see Dijksterhuis (1961), Garber (1992), Lennon (1993), and Osler (1994). Descartes published *Principia philosophae* in 1644. For discussions of Hobbes' contribution see Molesworth (ed.) (1962) vol. I., Mintz (1969), and Spragens (1973). Hobbes published *De corpore*, Part I of *The Elements of Philosophy* in 1655. For discussions of Cavendish's contribution see Mintz (1969) pp. 3-5 and Kargon (1966) ch. 7. For a discussion of Charleton's contribution see Sharp (1973). Charleton published *Physiologia Epicuro-*

corresponded with each other, reacted to each others' work, and formed an international intellectual community.[10] This community had a formative influence on the next generation of mechanical philosophers, such as Newton, Boyle, Leibniz, Pascal, Huygens, and Hooke.[11] However, all of these natural philosophies were premised upon the operational precepts of mechanical realism. Their disagreements were primarily based upon concerns with which interpretive metaphysics provided the most intelligible account of mechanical Nature and squared with their theological commitments. Mechanical realism had allowed the seventeenth century experimental and mechanical philosophies to be possible. It was then the task of the natural philosophers to build their interpretive metaphysics upon those precepts. The mechanical world-view was both an interpretive and operational metaphysical world-view in the sense that it was premised upon explicit assumptions about the constitution of the world in order to allow physical inquiry based on mechanics to be possible and intelligible. These assumptions involved explicit interpretations of reality in terms of contingency and necessity, the nature of matter, cause, and the ontology of the world, that reduced

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Gassedo-Charltoniana, or a Fabrick of Science Natural Upon the Hypothesis of Atoms in 1654. For a discussion of Digby's contribution see Foster (1988). Digby published *Two Treatises. In the One of Which, The Nature of Bodies; in the Other, the Nature of Man's Soule; is Looked Into: In Way of Discovery, of the Immortality of Reasonable Soules* in 1644. For discussions of Mersenne's contribution see Dear (1988) and Rouse-Ball (1960). Mersenne published *Quaestiones celebrimae in Genesim* in 1623, *L'impiété des déistes* in 1624, *La vérité des sciences* in 1625, and *Traité de harmonie universelle* in 1627. Descartes had met Mersenne at La Flèche during their education by Jesuits between 1604 to 1609 (see Dear(1998, pp.12-3; Garber (1992, pp.5-9) for further details.) Descartes also frequently communicated with Beeckmann, Constantijn Huygens (farther of Christiaan), William Cavendish, Jacques and Pierre DuPuy, Morin, Hnery More, and Gassendi (see Osler (1994, pp.118-9) for further details.)

[10] See Osler (1994) pp. 6-12, Mintz (1969) ch. 1, and Kargon (1966) ch. 6-8.

[11] For discussions of Boyle's contribution see Sargent (1995) and Shapin & Schaffer (1985). For discussions of Huygens' contribution see Westfall (1971) chap. 4 and Yoder (1988). Lennon and Osler argued that Gassendi and Descartes were the primary influences on the natural philosophies of Newton and Boyle; Kargon also included Hobbes. Osler (1994) pp. 9-10, Lennon (1993), and Kargon (1966) p. 54. Newton attempted to construct thought experiments to decide between Gassendi and Descartes in his early work and Boyle tried to accommodate both philosophies. See Westfall (1962) for Newton's early thought experiments; see also Boyle (ed. Birch, 1965) vol. 3, p.7. Newton was a committed mechanical realist but could not square his theological commitments with Cartesian mechanics. Newton tended to side with Gassendi regarding God's freedom and his corpuscular theory of matter. See Dobbs (1991) pp. 33-5. Elizinga (1972) argued that Huygens was greatly influenced by Descartes. Huygens accepted the precepts of mechanical realism in his methodology of physics and based his kinematics on Descartes' mechanics. For Huygens, any physical system could be reduced to a mathematical system of mechanics that could be understood with absolute clarity.

the conceptualisations of the physical to that of the mechanical motions of the six simple machines.[12] These assumptions were emergent during the developing understanding of, fascination with, and confidence in the possibilities and potentials of machines. The metaphysics of mechanical philosophy was reduced, in accordance with the limits of the mechanisation of processes, in such a way as to allow machines to have the power of disclosing natural mechanisms at work. This was possible because the conceptions of Nature had themselves been reduced to that of mechanical processes. In other words, the fundamental principles of Nature were reduced to be the fundamental principles of mechanics and consequently mechanics could be presented as the means by which the fundamental principles of Nature could be discovered. The circle was completed. It is this transformation, the emergence of mechanical philosophy, as expressed in the natural philosophies of Galileo, Beekman, Bacon, Gassendi, Descartes, Harvey, Newton, Hooke, Hobbes, and others, that was essentially premised on mechanical realism.

It was this new philosophical movement that began through the studies of mechanics, anatomy, and astronomy, during antiquity and the Medieval, and finally emerged in the sixteenth and seventeenth centuries as "new sciences". The (albeit limited) successes of the two mathematical sciences of astronomy and mechanics inspired the mechanical philosophers to propose that the motions of the entire physical world, the Heavens and the Earth, could be completely described in terms of laws, mechanisms, and inanimate matter. The physical world was to be described as nothing more than inanimate matter in motion in geometrical space – exactly the same components that comprised the conceptual basis of the rationalisation of mechanical devices. Newtonian natural philosophy became possible and Newton was able to assert that mechanics should not be limited to the manual arts, but, instead, be used to investigate "the forces of Nature" and to deduce the motions of the planets, the comets, the moon, and the sea.[13] In Newton's *Principia* we can find a statement of his precepts of presented as the "Rules of Reasoning in Philosophy."[14] Rule I is a statement of the natural economy of causes: "We are to admit no more causes of natural things than such as are both true and sufficient to explain their appearances." Newton presumed that "Nature does nothing in vain... for Nature is pleased with simplicity". Rule II is a statement the invariance and universality of cause-effect sequences: "Therefore to the same natural effects we must, as far as possible, assign the same causes." Newton assumed that Nature is both isotropic and homogeneous. This is an essential assumption for all experimental physics because without it the experimenter could not extend the particularities of any local experiment to the universal level of a law. Rule III is a statement of methodological reductionism: "The qualities of bodies, which admit neither intensification nor remission of

[12] Descartes seems to have been particularly aware of this reduction. He wrote in a letter to Florimond de Beaune (dated April, 1639) that all his physics was "merely mechanics". This reference was provided Miller and Miller (Descartes, *Principles* p. 52 fn 14) and was taken from the revised Adam and Tannery edition of *Oeuvres de Descartes* (Paris: Vrin/C.R.N.S., 1966-76, II, pp. 541-44).

[13] see Newton's Preface to the 1st Edition of *Principia* (pp. xvii-xviii). Motte's translation (revised by Cajori)

[14] *Principia* pp. 398-99.

degrees, and which are found to belong to all bodies within the reach of our experiments, are esteemed the universal qualities of all bodies whatsoever." This assumption was necessary for Newton to assert that "the qualities of bodies are only known to us by experiment" whilst simultaneously allowing the qualities determined through experimentation to be informative about bodies upon which an experiment has not been performed. Newton's own example was that of the Earth's gravitational attraction. If an experiment showed that a body attracted other bodies then Newton could use this demonstration to assert that all bodies attract each other. These precepts display considerable continuity with Newton's predecessors. In order to understand their connection with mechanical realism we need to examine their context of application. Newton founded geometry upon mechanics and told us (*Principia*, Preface to 1st. ed., p.xvii) that it "is nothing but that part of universal mechanics which accurately proposes and demonstrates the art of measuring. But since the manual arts are chiefly employed in the moving of bodies, it happens that geometry is commonly referred to their magnitude, and mechanics their motion. In this sense rational mechanics will be the science of motions resulting from any force whatsoever, and of the forces required to produce any motions, accurately proposed and demonstrated." For Newton, all causes of motion were mechanical causes and, consequently, his rules of reasoning are a statement of the precepts of mechanical realism. Hence the mechanisms disclosed through the mathematical projection of machines could be taken to be both the universal mechanisms of Nature and as methodologically available as solutions to the problem of transdiction.

Similar views can also be found in the works of Boyle and Hooke. Boyle, in *Mechanical Qualities* (1675), sought to explain cold, heat, magnetism, and all other natural phenomena in terms of mechanical principles. For example, Boyle wrote

"That which I chiefly aim at, is to make probable to you by experiments, that almost all sorts of qualities... may be produced mechanically; I mean by such corporeal agents as do not appear either to work otherwise than by virtue of the motion, size, figure, and contrivance of their own parts (which attributes I call the mechanical affections of matter)."[15]

This is also evident in the case of his development of the air pump as a means to disclose the fundamental nature of (already presumed) homogeneous and isotropic space as a vacuum (or void).[16] Once the technological innovation of this device was established (transformed into a reliable technological means of disclosure) then subsequent innovations and modifications could be woven into the social fabric of material science. This weaving was rhetorically secured to Boyle's natural philosophy on the basis of the social success in establishing the air-pump as a repeatable technological device. In fact, for Boyle, the knowledge that could be obtained from constructing and performing experiments was itself provisional on its use in the

[15] *The Works of the Honourable Robert Boyle*, 1672, Birch (ed.), vol. III, p.13.

[16] Cf. Grant (1981) and Shapin & Schaffer (1985).

construction and operation of future experiments.[17] For Boyle, the epistemological criterion for any knowledge claim was that it could be *instrumentally transdictive and functional* in the subsequent innovation of further machines. It was this epistemological criterion that was to become central to the whole methodological enterprise of experimental physics.[18] Hooke described an experimentally based mechanical philosophy of Nature as "the real, the mechanical, the experimental philosophy".[19] This "natural" philosophy had transformed from the observational, experiential, and categorical, into an interventionist interference with natural entities using instruments and machines to produce explanations of the sensible phenomena of experience in terms of fundamental mechanical interactions. Hooke's experimental mechanical philosophy was premised upon an intimate relationship between mathematics, natural philosophy, and machines. Hooke frequently used machines to present illustrations of "the common rules of mechanical motions" that he assumed were the mechanical principles of Nature. Newton, Boyle, and Hooke's work, in which machines were presented as having explanatory power about Nature, were all premised on the precepts of mechanical realist metaphysics. Newton, Boyle, and Hooke were able to assert the dream of deriving the rest of the phenomena of Nature from the same kind of reasoning from mechanical principles. This dream was only possible once Galileo and the sixteenth century mechanists had assumed the metaphysics of mechanical realism. However, in the seventeenth century mechanical philosophies, mechanical realism was itself transformed. Once secured, there was not any further need of the metaphysical arguments of the sixteenth century mechanists. Once the status of mechanics had been transformed from a banausic art to a natural science, by the mathematical projection of the six simple machines as geometrical demonstrations, then those first principles could be presented as "eternal and necessary truths". In combination with the mechanical realist metaphysical premise that "natural causes" were efficient, this transformation allowed mechanics to be naturalised. The distinction between the artificial and the natural was dissolved for particular aspects of technology: the fundamental principles of mechanical motion. That was subsequently taken as self-evidently true and there was not need of any further metaphysical argument. Once this had been achieved then the ontology of experimental physics, based on mechanical apparatus, could achieve an epistemological legitimacy as a means of disclosing truth. Mechanical realism had become techno-ontological: it was a means of disclosing the truth and nature of beings. The "scientific revolution" of the sixteenth century was the mechanists' revolution that was founded upon the establishment of mechanics as a mathematical science and was directed towards the establishment of the epistemological legitimacy of mechanics as a natural science. The establishment of this legitimacy involved a transformation of the conceptions of matter, cause, natural necessity, and the dissemination of the mechanical world-view, in parallel with rhetorical appeals to the practical successes of

[17] Shapin & Shaffer (1985) chap. 2

[18] A view that was central to Ian Hacking's (1983) *instrumental realism* and Bhaskar's (1975) *transcendental realism.*

[19] Hooke, *Micrographia* (London, 1665), preface, quoted in Bennett (1986) p.1.

mechanics. It was also premised upon novel conceptions of "Man" and "rationality".[20] Furthermore, the reduction of the lived-world to the mechanical world required a distinction between primary and secondary qualities. The former were taken to be those properties possessed by material bodies whereas the latter were taken to be the effects due to the interaction between material bodies with human sense organs and minds. This distinction was required to account for the fact that human experience is not of a mechanical world (an accounting that was itself a transdiction) and also provided the possibility of a mechanical account of human perception. It required a fundamental transformation in the conception of the human body.[21] With the increasing interest in the development of the mechanical sciences in seventeenth century Europe, for the purposes of enhancing technological powers, the discourses of mechanical natural philosophers become dominant. Once this occurred then the path was cleared for the notion of "mechanism" to become the dominant explanative trope. This monolithic explanatory strategy was symptomatic of the accelerated mechanisation of European social organisation towards the monolithic goal of achieving technological advantages for the competing European social elites. This transformation was a profound shift from the contemplative scholarly logic and poetics of Aristotelian (and to some extent neoplatonic) natural philosophy towards the construction of mathematically rationalised machines and transformative technological powers. As I argued in the last chapter, Aristotelianism had become obsolete and irrelevant.

Osler (1994, ch.10), following Kuhn (1977), argued that two distinct traditions, or "styles", emerged from the mechanical philosophies of the seventeenth century.[22] She argued that these two

[20] Cf. Steigler (1998) ch. 3 for a discussion of the seventeenth and eighteenth centuries conceptions of "Man" in relation to both Heidegger and Ellul's conception of technology.

[21] I shall return to this point in chapter six.

[22] Osler's argument was that these two traditions emerged from two distinct theological traditions, exemplified by in Gassendi and Descartes' natural philosophies, and these lead to the two distinct approaches, empirical and mathematical, in the latter part of the seventeenth century. She considered the development of mathematical and practical trajectories of science to be a consequence of the Descartes vs. Gassendi arguments on God's relation to natural laws and necessity. Gassendi argued that all natural phenomena could be explained in terms of atoms of inanimate matter and their motion in geometrical space. His atomism was based upon the ancient atomic theories of Epicurus and Lucretius and he argued that the Universe is composed of atoms and the void. He argued that atoms possessed the qualities of size, shape, and heaviness, and consequently cannot be described in terms of *a priori* knowledge. His theory of science was based on appeals to experience and also the assumption that essences were knowable only to an absolutely free God. On the other hand, for Descartes, size, shape, and location, were the primary qualities and, since these were all geometrical properties, then the essence of a material object could be known through mathematical reasoning. God, being perfect, was unchanging, and therefore, the mathematical laws of the Universe, created by God, were themselves perfect and unchanging. It was not a question of whether God *could* change these perfect laws. Once God had created the laws of Nature then God *would* not change them. Osler was aware that Hacking (1982, 1992) has raised considerable objections

"traditions" exemplified and manifested themselves in terms of two distinct sets of scientific practices governed by distinct metaphysical and epistemological assumptions. These two sets of scientific practices were termed by Osler to be "conceptual frameworks" which differed in the emphasis that they placed on empirical evidence and mathematics in their interpretations of natural phenomena. However, in my view, this distinction conceals an essential unity in the development of scientific practices since the seventeenth century. These two "conceptual frameworks" were primarily derivative from the same mechanical realist metaphysical precepts and, as such, were the two dimensions of the same "technological framework". The mathematical dimension was more apparent in the grandiose mechanical realists, such as Descartes, Galileo, and Newton. Their problems involved developing a mathematical description of the entire Universe, whereas the practical dimension was more apparent in the modest mechanical realists, such as Boyle, Pascal, and Newcommen, whose efforts were directed towards developing particular machines in order to solve particular problems. These two dimensions were derivative from the establishment and acceptance of mechanical realism as different sides of 'the same coin' and did not constitute distinct "conceptual frameworks", paradigms, or metaphysical positions. They merely constituted a degree of difference in attitudes regarding the "new science" and its possibilities. As such, this difference is indicative of a spectrum of dispositions regarding the question of what could be achieved with the "new physics" rather than *necessarily* constituting formally assumed metaphysical positions.

Without a formal metaphysics, dispositions do not form "conceptual frameworks" about the world, even though they may well be formally transformed into them, but, rather, constitute different tendencies towards acting *within the world.* I agree with both Kuhn and Osler that the "empiricists" tended towards practical problem solving and the "rationalists" tended towards the development of interpretive metaphysics. However, a form of mechanical realism was presupposed by both approaches and, in my view, both Osler and Kuhn have missed the unitary essence that connected these two dimensions.[23] In my

to the utility and meaningfulness of the word "style" to characterise endeavours in scientific reasoning. In my view, "priority" constitutes a clearer term for discussions of the distinction between practical problem solving and grand cosmological theorising. Perhaps the term "style" should be reserved for the forms of writing and presentation, which have been developed to convey scientific narratives. Cf. Derrida (1967).

[23] Of course it is possible to find particular cases, such as Boyle's arguments with Hobbes concerning the interpretation of air-pump experiments, in which the dispute can be stretched between Gassendi vs. Descartes poles. Cf. Osler (1994) p.225. However, this dispute was not a rationalist vs. empiricist dispute, nor mathematics vs. experiment dispute, but was specifically a plenum vs. void dispute, and, as such, was not necessarily a typical dispute. A commitment to mechanical realism was premised in both Hobbes and Boyle's arguments. I accept that the content of these arguments involved, as Osler argued, theological commitments, such as More's commitment to "the Spirit of Nature" and Boyle's rejection of it. Osler (1994) p. 226. See also Shapin & Shaffer (1985) pp. 207-12. These may well have been prior to the interpretations of the air-pump experiments, and conceptualisations about Nature, but it does not follow that either of the arguments should be construed as clearly empirical or rational. Hobbes, and More, tended

view, once mechanical realism had become established (which it certainly had become by the latter part of seventeenth century) then, in experiments, both mathematics and technology had become integrated into physics. The content of both mathematics and experience had been transformed by the mechanical realist precepts and the techniques utilised to disclose "natural mechanisms". Mechanical realism had been used to justify the reduction of the experienced world into mechanically accessible properties that could be mathematically projected over parts of the world and presented as the whole world. Empirical evidence was restricted to variables and quantities that *in principle* could be measured using mathematically rationalised and calibrated technological devices (scientific instruments) even though it was not necessary that they were actually measured *in practice*. Mathematical treatments were limited to forms that could be both abstracted from mechanical devices and used instrumentally in the design, building, operation, and interpretation of such devices. Experimental apparatus, as means of disclosure, were based on the interaction between mathematics and machines and both "traditions" were based on the same assumptions. Furthermore, due to the mathematico-technological structure of the new physics, neither "tradition" could be placed under experimental test in terms of the other. Any experiments devised to facilitate such a decision would require the very assumptions that were being "tested". Both "traditions" were based on mechanics, assumed mechanical realism, and consequently there was not any mechanical means, either in deed or thought, by which a decision could be made as to the superiority of the one approach over the other. Both the so-called empirical and the mathematical traditions were dimensions of the same "technological framework" in such a way as to centre the distinction between the priority of the usefulness of mathematics to experiment or of experiment to mathematics. Either way, the central constraint was that of the mechanisation of any hypothesis or proposition. These two dimensions are evident in Newton's approach in *Principia*.[24] It is this two-fold dimensionality that is central to experimental physics. It is evident in the

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towards grandiose (reductive) mechanical realism and, as such, held a metaphysical commitment that was not empirical, but Boyle's interpretation of the air pump was no more empirical than Hobbes' *a priori* assertion that the Universe was a plenum. Even if one accepts that a vacuum existed in Boyle's experiment, and it is questionable whether it did, it does not immediately follow from the localised production of a vacuum in a glass bulb using a pump that the entire Universe is comprised solely of atoms and void. Even Boyle was not prepared to go as far as even claiming that the space in his apparatus was really devoid of all matter, let alone use that experiment as providing any purchase on a universal truth claim. Boyle was possessed with a more modest form of mechanical realism than Hobbes and, as such, the dispute was not so much as whether mathematics or experiment was the correct path but rather that of how far one could go with either.

[24] Newton was an inductive empiricist in so far as he argued that all facts should be induced from experiment and re-evaluated in the light of further experiments. He was also a mathematical deductionist in so far as he argued that the demonstration of any truth should be deduced from mathematical first principles. It is also evident in his *Opticks* where the lens is itself reduced to an optical lever that

eighteenth and nineteenth century studies of mechanics, optics, thermodynamics, and electromagnetism. These distinct areas of physics all operated by reducing the motions of their respective objects to that of circles, anti-parallels, orthogonal reflections, levers, screws, and push-pulls. These were the motions abstracted from the six simple machines. However, these distinct areas of physics can not be reduced to one another because they involve distinct sets of stabilised mechanical processes using distinct kinds of materials. They are *strata* of distinct machine-kinds: mechanical machines, optical machines, thermodynamic machines, and electromagnetic machines. I term these *strata* as machine-families. How can these machine-families be characterised in such a way as to reveal a general principle by which practical experiments and mathematical theories can be linked and shown to be manifestations of the same "technological framework"? It is my argument that this general principle was the methodological principle of mathematically projecting the abstracted motions of the six simple machines (the first machine-family) over all subsequent machines-families. This is done during the innovation of those machine-families as stable and repeatable disclosures of mechanisms whilst maintaining their distinction in relation to the kinds of materials from which those machines were built. In order to make this argument I need to return to Heidegger's characterisation of modern science as mathematical projection.

Heidegger (1977b) argued that Nature is transformed by modern science into the object of explanatory representation *and only that which can be objectified* is considered to be real within scientific research. The objectification of Nature is accomplished, according to Heidegger, by setting in place, representing, each particular being that can be objectified in such a way that calculation provides certainty of the reality of that being. Modern scientific research was only possible *when and only when* truth had been transformed into the certainty of calculable representation. Heidegger located the transformation of this conception of truth in the metaphysics of Descartes (as articulated in *Meditationes de prima philosophia*). For Heidegger, (1977b, p.127) the essence of the modern age was to be "seen in [the] fact that man frees himself from the bonds of the Middle Ages in freeing himself to himself." Heidegger's analysis of the characteristics of the essential foundation of the modern age held "the modern world picture" (*Weltbild*) to be central.[25] In this context, Heidegger used the word "world" to refer to "what is, in its entirety" and did not limit it to "the Kosmos", or "Nature", or "History", or "Matter". He used the word "picture", not in the sense of a copy or imitation, but, rather, in the sense of the colloquial expression "get the picture", to capture the way that we grasp the matter in question. "The world" in this case, in place before us, as a representation, and all that belongs to it and stands together in it, is a system, in such a way that we are acquainted with it as something that we are equipped and prepared to deal with. Thus "the

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mechanically operates upon (otherwise) rectilinear rays of light. This is also evident in treatments of the phenomenon of polarisation, which is treated in terms of the wheel and the lever template.

[25] 1977b, pp.128-34. Lovitt noted (p.128 fn 12) that *Weltbild* is conventionally translated as "conception of the world" or "philosophy of life" but the literal translation as "world picture" was more appropriate in the context of Heidegger's discussion. However, in this context, "conception of the world" also bears a close relation to the theme of Heidegger's discussion.

world picture" was presented as that which we are prepared for and which we intend to bring and set in place before us as something conceivable (graspable). This setting in place, representing, of *the world as picture* involves an essential decision regarding what is, in its entirety. It is an anticipatory act of mathematical projection. It was this setting in place, as something objectively before us and at our disposal, that was, for Heidegger, characteristic of the modern age. There was not an ancient or medieval "world picture" that was transformed into the modern; having a "world picture" at all is characteristic of the modern age. Heidegger argued (1977b, p.134) that this "picture" was produced in such a way that it represents to us, gathers and orders, an image of the world that affords us the position of articulating, securing, and organising a "world-view". This allows us to measure and draw up the guidelines for everything that is in accordance with our "unlimited power" for the planned calculation and manipulation of all things.[26] For Heidegger, (1977b, p.135) scientific research is an "absolutely necessary form of this establishing of self in the world", because it provides a graspable picture of the world in which the self can be situated as the one who grasps. It was this picturing which participated in the set-up of the modern age, and science "is one of the pathways upon which the modern age races towards fulfilment of its essence, with a velocity unknown to its participants." As such, the mechanical realist metaphysics of modern science and modern technology was foundational for the modern age and is a central participant in the development of modern culture.

However, this still leaves us with the question of how a "world-picture", a "mechanical world-view", connected theoretical and experimental practices. How was the "world-picture" mathematically projected over phenomena, in such a way as to make them graspable and calculable in advance, in terms of mechanical principles? How are theories and experiences connected within the "technological framework" of experimentation?

Setting-Up The Ground-Plan:

Modern experiments, such as those performed at CERN and by the ULT physics group, are technologically sophisticated projects involving a wide range of techniques, practices, machines, tools, tacit skills, and knowledge. The objects experimented upon, such as "electromagnetic fields", "paraelectric materials", "photons", "nuclei", "quasi-particles", "electrons", "quark-antiquark events", "superfluids", etc., require techniques and machines for their production, observation, and manipulation. Without those techniques and machines we would not be "aware" of these objects at all. The relationship between scientific experience and these "invisible" objects occurs by transforming the macroscopic objects of everyday experience into a means of disclosure. Physicists are concerned with macroscopic objects, such as machines, because these technological objects disclose the underlying causal mechanisms in operation in those machines. The object of scientific inquiry is not the machines themselves but, rather, the *techno-phenomena* that are produced by

[26] Obviously it is possible for the mechanical realist to object to Heidegger's characterisation on the premise that "our power" is, in fact, limited. Is it? If so, then why? The mechanist will pronounce "Natural Law" as if that, in itself, explained anything. I shall discuss this in chapter six.

those machines.[27] Many of the phenomena studied by contemporary physicists are *techno-phenomena*.[28] The properties of superfluid He-3, the dynamics of phonons in crystals, the thermal capacities of metals, the properties of lasers, superconducting materials, solar neutrinos, the polarisation of the tau-lepton, etc., are all complex objects which are only disclosed through the mediation of machines, theories, and techniques. The establishment of scientific facts and theories about such objects requires putting techniques to work. Furthermore, these objects are only objects for study because machines, theories, and techniques have been put to work. Without putting machines, theories, and techniques to work these objects would not be apparent at all, and, would not be available for scientific study nor philosophical discourse. Theories are bound up with both the objects of study and the techniques by which they are investigated. Otherwise there would be no possibility of putting them to "the test". The observational aspect of experimental work involves the active technical use (and modification) of theories, methods, and techniques. It is complex and there is not any possibility of being able to disentangle theories, techniques, and observations, *except in*

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[27] The term *phenomeno-technique* has been attributed to Gaston Bachelard, and there seems to be a considerable parallel between this idea and that of *techno-phenomena*. I have two reservations about a parallel here: (i) Bachelard seems to have been a scientific enthusiast; (ii) I have not read his books. Unfortunately, English translations of Bachelard's books on science are unavailable until, at the earliest, the end of this year (2001) when Clinamen Press plans to publish *Formation of the Scientific Spirit*. I have consulted Gaukroger (1976); Lecourt (1977); Tiles (1984), and have noted several promising parallels between Heidgger, Bachelard, Gooding, and my own approach. Unfortunately, I am not in a position to discuss them yet. His works on science (in French) are: *L'Activite rationaliste de la physique contemporaine*, Generale d'Editions, 1977 (Paris: Presses Universitaires de France, 1951); *Le Nouvel Espirit scientifique* (14th ed.) Paris: Presses Universitaires de France, 1978 (Paris: Alcan, 1934); *Le materialisme rationnel* (3rd ed.), Paris: P.U.F., 1972, (Paris: P.U.F. 1953); *La Formation de l'espirit scientific: Contrabution a une psychoanalyse de la connaissance objective* (11 ed.), Paris: J. Vrin, 1980, (Paris: J.Vrin, 1938); *La Philosophie du non: Essai d'une philosophie du nouvel espirit scientific* (7 ed.), Paris: P.U.F., 1975, (Paris: P.U.F., 1940); *Le Rationalisme applique* (5th ed.), Paris: P.U.F., 1975, (Paris: P.U.F., 1949)

[28] Examples of technophenomena explored by the Lancaster ULT physics group are: Magnetization of absorbed He-3 films: Bäuerle *et al.*, (1995); Shaw *et al.*, (1998b); Absorption of He-3 on graphite: Bäuerle *et al.*, (1996b), 3He/Graphite Antiferromagnetic Regimes: Bäuerle *et al.*, (1996d); Nuclear Magnetization of He-3: Bäuerle *et al.*, (1996e); Heat Capacity: Bäuerle *et al.*, (1997), Resonance of Landau Field: Bunkov *et al.*, (1992a, b); Spin precessions: Bunkov *et al.*, (1992c, 1994); Quasi-particles: Bunkov *et al.*, (1992c); Nuclear Magnetic Resonance (NMR): Bunkov *et al.*, (1995b, 1996); Temperature Dependencies: Cousins *et al.*, (1994); Andreev Scattering/Reflection of Quasi-Particles: Fisher *et al.*, (1990a, 1992b, c, d); Enrico *et al.*, (1993); Cousins *et al.*, (1995b, 1996b); A-B superfluid phase boundary: Fisher *et al.*, (1991c); Cousins *et al.*, (1996c); Nuclear spins: Enrico *et al.*, (1994a); Cousins *et al.*, (1999); Vibrating wires: Fisher *et al.*, (1991d).

hindsight through reconstruction.[29] Take He-3 for example. This isotope of the element helium is itself a product of technological processes. It is the by-product of the nuclear weapons industry and (to a lesser extent) the oil production industry. I am not claiming that helium does not exist naturally but "natural helium" is not what is being experimented upon. A physicist would explain that there is an absence of helium in the atmosphere.[30] He-3 is only available as a result of the above mentioned industrial processes. Furthermore, the Lancaster ULT physicists do not directly experiment upon *that* He-3. What they experiment upon is a purified sample of that He-3. By what standard is "purity" defined here? "Purity" is defined in terms of an established technique of purification and, in order to know whether a sample is pure or not, the experimenters must do so in relation to that technique. This anticipates what He-3 is to be and that which passes through the template will be He-3. Thus helium is transformed from a "natural substance" to a technological product, via techniques and machines, and it is the latter that is experimented upon. Mechanical realism cannot secure itself on a theory of natural kinds because the objects of experimentation are modified according to kinds of technique. Furthermore, the properties of He-3 disclosed by the experiments of the ULT group are only those that can be disclosed using the techniques of dilution refrigeration and voltage resonance. Anything else will remain unobserved and not be part of "their" He-3. Thus the He-3 explored is not He-3 in its entirety, as a "natural substance", but is, in fact, the *techno-phenomena* of the theoretically interpreted interactions between machinery and the technological product

[29] Examples of the use of techno-phenomena, innovated and stabilised as techniques by Lancaster ULT group, to explore other techno-phenomena are: magnetic field dependencies: Fisher *et al.*, (1991b, 1992a); Bäuerle, *et al.*, (1995, 1996e); nuclear magnetic resonance (NMR): Bunkov *et al.*, (1992a, b, 1995b); Bäuerle, *et al.*, (1996a); Cousins *et al.*, (1999); nuclear recoil: Bradley *et al.*, (1995b) thermal boundary resistances: Cousins *et al.*, (1994, 1995a, 1996a); A-B phase boundary movements: Cousins *et al.*, (1995b, 1996b); Andreev reflection of quasi-particle beams: Enrico *et al.*, (1994d, e); Cousins *et al.*, (1996c, 1997); Shaw *et al.*, (1996, 1998a); vibrating wire resonances: Fisher *et al.*, (1990b, 1991a, 1992c). Examples of modelling techno-phenomena and techniques in terms of other techno-phenomena: Cosmic string formation: Bradley *et al.*, (1995a); Bäuerle *et al.*, (1996a, b, 1998); Quantum gases: Fisher *et al.*, (1992e, 1994); Pickett *et al.*, (1994); Cousins *et al.*, (1997); Damping forces: Enrico *et al.*, (1994c, g); Superfluids: Morchard *et al.*, (1995, 1996); Fisher *et al.*, (1989).

[30] This absence is explained by the transdiction that helium is lighter than air and would escape into space. A physicist would construct a device to demonstrate this transdiction by establishing a technique by which it could be shown that there was helium and air present in the experiment and that the helium was, in fact, lighter than the air. This device could then be presented as a model for the Earth's atmosphere on the basis of the mechanical realist precepts that Nature operates by mechanical cause-effect sequences; that there is a single mechanism between each cause and each effect, and that these mechanisms are in operation in both the device and the atmosphere. A deviation in the performance of the experiment from the model can be explained by further transdiction. A further interfering mechanism can be sought and the model can be modified.

He-3. Furthermore, He-3 is studied by the ULT group, not for its own sake, but for the sake of understanding the *quantum properties of superfluidity at ultra-low temperatures.* The *techno-phenomena* of the technological product He-3, within the "technological framework" of the experiment, are a means of disclosing these properties. They are taken (again invoking the precepts of mechanical realism) to be realisations of the transfactual quantum mechanisms that are independent from He-3 and are otherwise swamped by impurities and higher energy interactions. He-3 is used as a technological object to disclose these subtle mechanisms because it is taken to be the bounded technically rational choice on basis of its functionality within the technologies at the physicists' disposal.

Techno-phenomena are phenomena that have been brought into the world by machines and techniques; the scientific experience of these objects is circumscribed by their responses to technical interventions and interpretations of how they have been disclosed. They are disclosed by the theoretical interpretation of machine performances and their availability for theorising is dependent upon those machines. Each *techno-phenomena* is *existentially* dependent upon the machine-family within which it occurs and, as such, the history of its becoming an object for scientific investigation is a part of the history of the construction of that machine-family. For example, an "electromagnetic field" is a *techno-phenomenon* that is dependent upon the existence of electromagnets and "electric current" production machines (these, in turn, are dependent upon metal production techniques and chemistry, and so on). It is disclosed by integrating those machines together, into a single unified technological object, by utilising specific techniques and interpretations of how those machines work. The "electromagnet" is a technological object available to produce an "electromagnetic field" only as the result of considerable efforts by experimentalists such as Oersted, Davy, Faraday, *et al.* However, contra Hacking, we cannot base a realism upon this stable instrumentality. The performance of any technological object, as a productive object, is itself dependent upon explanatory accounts of that performance and what it has been taken to produce. Thus "spraying electrons on mobidium spheres" is an act of interpretive reference to a manipulative technique made in relation to a machine built in order to disclose "fractional charge". "Fractional charge" is itself an index for a set of particular machine performances that would achieve their theoretical significance, as instances of "free-quarks", through the embodiment of theoretical significance in the selection of techniques and technological objects collected together to construct the machine in the first place. It does not follow from the stability of those machine performances that the interpretations of them are correct. That is the very question at stake. There is an interpretive dimension to machine performance and a technical account and technological object should not be divorced from one another. Objects, such as the "electromagnetic field", are defined in terms of what they do, their functions and interactions in specified contexts, and, as such, the concrete character of their performance is inextricably bound-together with technical interpretations of that performance. The "electromagnetic field" is neither purely abstract nor purely concrete. It is both. The performance and accounts are made "hand in hand" through their concrete implementation in the particularities of practice. Each *techno-phenomena* is a set of complex machine performances (voltages, time-signals, frequency resonance, etc.) unified under a single index (i.e. electron, charge, repulsion, energy gap, field change, etc.) in such a way as to link theoretical interpretations with technical interpretations of those machine performances. Of course the scientific realists and positivists will object at this point. Does not lightning produce an electromagnetic field? That is the question. Without wanting to conflate epistemology with ontology, I would like to ask another. How do we know that lightning produces an electromagnetic field? "Physicists have measured it!" reply the scientific realist and the positivist in unison. Therein lies the rub. *How have physicists measured it?* This question is central to the understanding of experimental science presented by Heidegger and Gooding.

Heidegger characterised the essence of modern science as in terms of three "fundamental events": *mathematical projection*, *research*, and *on-going activity*. I discussed mathematical projection in the last chapter. In this chapter I shall discuss the other two "fundamental events" and their relation with mathematical projection. Heidegger (1977b, pp.118-21) discussed research in his essay *The Age of the World Picture*.[31] What is scientific research? For Heidegger, (1977b, p.118) the first essential characteristic of research is the opening up of a sphere of research, in which procedure can operate and provide knowledge. This is done by projecting a "fixed ground plan of natural events" over Nature in such a way as to sketch out, in advance, the connection between procedure and the opening of the sphere. How is this done? Heidegger did not give any account of this. How is the opening of a sphere of research and procedure connected by the advance sketching of a fixed ground plan of natural events? David Gooding in *Experiment and the Making of Meaning* (1990) described how Michael Faraday, *et al.*, did exactly this. Gooding's analysis of the development of the stable communicable results of the work by Faraday *et. al.* is a history of the considerable effort involved in the development of stable craft practices and representational techniques. Gooding argued that experimenters, such as Faraday, were engaged in a process of developing communicable and stable representations that enabled reasoning and skills by conferring meaning upon actions, materials, instruments, and procedures. He deconstructed the orderly reconstruction of the post-experiment narratives of the nineteenth century physicists, which are presented in publications of results and notebooks, in order to recover the processes involved in generating order in the face of the phenomenal chaos of novelty. His analysis showed that these narratives and representations emerged as a result of nonverbal material practices directed towards the construction of cognitive representations through the refinement of those practices. He argued that the theory of electromagnetism was made, rather than discovered, and it has no fixed, independent, essential nature that can be accessed independently of the manipulations that are involved in the development of stable practices and representations. He also argued that the phenomena disclosed by Faraday *et al.*, and the effects that these physicists encountered on the way to producing those means of disclosure, are not "mere fictions" either. He proposed a convergence theory of agency, which he termed "asymptotic realism", in which experimental practices (manipulation) and theoretical practices (representation) converge when both types of practice acieve practical success in

[31] In this essay, Heidegger maintained the position given in *Modern Science, Mathematics and Metaphysics* (1999b), as a starting point. *The Age of the World Picture* should be read as a development of the analysis given in *MSMM* in order to provide a "deeper" and clearer understanding of the essence of modern science.

making models that enable experimentation and communication. He used the analogy with the mathematical asymptote to convey the point that at no time is an independent Nature touched. (1990, pp.186-8) This convergence is directed towards the innovation of stable, reasoned, material practices and experiences of producing novel phenomena. To put this point into my terms, Gooding seems to have characterised experimental physics as directed towards the acquisition of a *techne*.

On Gooding's account of experimentation, intervention is central. Experimentation occurs through planned interventions upon objects in the world. This intervention is itself guided by the experimenter's conception of the object and the world. Through progressive actions, the object, the conception of the object (and the world), and the experimenter's conceptions of how to intervene are transformed. Experimentation dynamically creates new phenomena and conceptions of the projected plan of action. Through experimentation, objects and the dynamic process are brought into being. It was this view of the dynamic, creative, and technically rational process of experimental science that seems to have put Gooding in opposition to scientific realism. In my view, Gooding's use of the term "asymptotic realism" to describe the psychologism that results from the achievement of stable processes of refinement, seems to belong with the realist notion of "approximation". However, what Gooding has done is to highlight the extent that the notion of "approximation" is itself only meaningful within the context of both a history of refinement and also *a projected future* to an unattainable limit. In my terms, this reveals the extent that scientific realism is itself bound-up with its metaphysical faith in the challenge of the becoming of the "bringing-forth" of a perfection that is never achieved in practice.[32] For Gooding, objective knowledge is open to change and is made. The idea of experimental physics exploring a reality independent of it is only possible from a removed and abstract level *after the real work has been done*. Scientific realism is an obstacle to us developing a deeper understanding of the processes by which experimenters realise their reasoning and manipulative possibilities. Experimentation aims at objective knowledge, but what constitutes such knowledge, and rationality itself, must be learnt along the way. A change in experimental practice may involve a change in understanding as to the nature of knowledge and its method of acquisition. Furthermore, any understanding of any measurement can only be developed, through experimentation, in relation to an understanding of the techniques by which that measurement was made. It is for this reason that statements of the degree of precision (and confidence in those statements) are linked to evaluations of the sensitivity and "cognitive value" of the techniques used.

For Gooding, progress was both a technical, functional, pragmatic, revisable, and creative goal of all scientific activity: a perpetually emergent (and idealised) trajectory towards objectivity. Claims to increased accuracy in measurement can be considered to be justifiable despite the facts that they are (1) based upon theory-dependent techniques, and (2) they cannot be compared to any absolute standard. The justification of such claims is based upon the convergence between theoretical and experimental practices

[32] I shall discuss this further in chapter six.

in which the measured quantity is involved.[33] It seems that Gooding's characterisation of the basis for scientific judgements of convergence was a conception of rationality in terms of a bounded and evolving technical rationality that was directed towards an unobtainable complete causal account of the activities of experimental and theoretical practices as an ideal. It is in this context that the goal of experimental practices can be taken to be the achievement of its own *techne*. Consequently, the standard by which scientific practitioners are to judge their own objectivity is to be in reference to "the cognitive value" of their own judgements within a context of "making". This objectivity requires a social agreement between all (similarly placed) experimental practitioners. It is made through the innovation of novel modes of reflection, discourse, representation, and material practice (and not through immediate intuition, nor experience). Gooding did not deny that experience has a qualitative uniqueness, but he did not consider this to be objective, because this uniqueness cannot be shared. He consequently maintained that such experiences have nothing to do with "the material world" where that "world" was circumscribed as being that which is disclosed through publicly accepted techniques of manipulation and representation. "Objectivity", as a socio-technical pursuit, stands in opposition to the "self-evidence of experience" because it must be demonstrated to another by using a mutually understood technique. Experimental physics, as a historical phenomenon, is itself constantly undergoing change, in its theories, objects, and techniques, and, for Gooding, change is an essential part of the rational process of scientific inquiry. "Subjective experience" may well have a role in instigating change but that change could not become part of science until it had been publicly justified via accepted techniques. Thus, for Gooding, an observation made by an experimenter could only become part of science once it had been justified to the experimenter *and others* in terms of repeatable observational techniques. It seems to have been for this reason that Gooding rejected the positivists' appeal to perception, because what was required for "objectivity" and rational discourse was a justification of any perception made in relation to technique. Even at the level of measurement there is always the possibility of future refinement and the development of new techniques and instruments. There is no such thing as "fixed data" because "data" is acquired through the use of techniques and there is no such thing as a technique that cannot be refined. Empirical inductive reasoning requires the applicability of concepts to objects and, thus, if empiricism is to be successful, it requires the successful and complete refinement of those concepts in relation to the objective world. However, on Gooding's account, such a process of refinement is never complete and the empiricist is dependent upon the work of others. Gooding's argument against positivism (and classical empiricism) was that they have misunderstood the practicality of theorising, neglected the relevance of knowing-how to knowing-that, and that the interdependence of know-how and know-that is just as necessary to defending empirical claims as it is to explaining their origin. At the point of the asymptotic (unreachable) point of perfection the object under investigation will be considered to be completely understood, absolutely stable, and functionally

[33] Examples of the ULT physics groups' papers on the technological innovation of nuclear cooling techniques are: Enrico *et al.*, (1994b, f); Fisher *et al.*, (1995); Bunkov *et al.*, (1995a); Bäuerle *et al.*, (1996f, 1997).

repeatable. It will be a robust technological object available for future use and will no longer be an object for experimental investigation (except as an object used to investigate other objects). Experimenter's are not engaged in simply (and passively) registering what is objectively the case because they are actively using techniques, and making judgements about which technique to use, when performing experiments and making observations. It is for this reason that experimenters write down accounts of which techniques they have used. Scientific journals would not accept a paper that merely recorded "observations" without reference to techniques. Experimental observation requires the development of observational skills and if others are not able to acquire these skills then it is unlikely that the experimental observations will be widely accepted.[34]

Even when a novel experimental phenomenon is not theoretically understood it still can be known under publicly available technical descriptions. Both the intentions and the techniques implicated in the experimental set-up (the construction of the experiment, its operation, and its theoretical significance) can be known without a complete theoretical description of the phenomenon. Otherwise there would not be any point in performing the experiment. Nor would the experimenters be able to anticipate the phenomenon and devise a plan of action. For Gooding, experimentation is founded on a projected plan of action, which anticipates the phenomenon. However, one of Gooding's main points was that when physicists attempt to experiment upon novel phenomena they need to be able to understand one another and so agree about the object of their investigation. This involves coming to an agreement about what phenomenon is under investigation, what they want to learn about it, and how to proceed to learn that. *These decisions are made as the investigation proceeds and are not completely fixed in advance.* Experimenters learn how to articulate their experiences of novel phenomena along the way of experimenting upon them. Experimental investigation involves the progressive organisation of the research, the techniques, the resources, and the descriptions of experiences. Novel phenomena require novel forms of communication and representation in order to reassure the experimenters that they are experimenting upon *the same thing*. This involves producing agreement about the methods of experimentation and also about what was experienced when those techniques were implemented. For Gooding, if we are to grasp what a scientific object is (i.e. an "electromagnetic field"), *as an object of knowledge*, then we need to know how that object has been cognitively engaged with and how cognition was achieved. In the case of Faraday's experiments, this involves paying attention to the social and material practices that were developed as the work progressed, and the way that theory is created rather than discovered. At each stage of experimental research the experimenters publicly tie together techniques (both manipulative and representational) and *techno-phenomena* that are brought into the public realm through those techniques. This involves a progressively

[34] Consider the case of "cold fusion". Fleischmann and Pons were unable to publically provide a repeatable technique of how to observe "cold fusion" and, consequently, the validity of their work was brought into question. Collins (1985) also made this point about experimental efforts to observe gravitons (and also emotional responses in plants). The experimenters' inability to publicly provide a reliable observational technique undermined the scientific confidence in their observations.

developing refinement of "the ground-plan of Nature" as part of the reiterative process of drawing up a plan of action for how the research is to proceed.

For Heidegger, the rigor of research is the obligation to remain within the opened sphere and, by projecting the ground plan and prescribing rigor, the procedure is provided with a sphere of objects (an object-sphere) appropriate to that procedure. Heidegger did not provide an example of an object-sphere. I take it that an object-sphere is the collection of objects upon which procedure (a connected set of techniques) operates. An example of this would be the phenomena under investigation during an experiment on electromagnets, such as coils, wires, batteries, and magnetic needles, as well as the deviations in magnetic needles when they are moved adjacent to the connected coils and batteries. The procedures would be the techniques for connecting these objects and investigating the contours of the deviations. Mathematical physics anticipated in advance the plan (projection) required for the procedural knowledge of Nature as material corporeality in its motion. The rigor of modern physics is defined in terms of its exactitude because it must restrict itself to calculative research performed in this way, in order to remain connected to its object-sphere, and not merely because it calculates with precision. Heidegger was being more general than Gooding. He was referring to all of physics rather than the early experiments on electromagnetism. Nature, as the projected ground plan, became the "self-contained system of motions of units of mass related spatiotemporally" (1977b, p.119). He was referring to the whole Newtonian schematics that had been established as the exemplar of physics, in which motion was defined as the homogeneous and isotropic change of position in a projected grid of space and time, and force was defined in terms of the magnitude of change of position in this grid. Every event in Nature was defined in advance *as an event* only in terms of how it could be made visible within the projected ground plan. The projected plan is guaranteed by restricting research to the projected plan in every one of its questioning steps. All events had to be defined as spatiotemporal magnitudes of motion and changes of motion that were quantifiable through measurement and calculation. In this respect the experiments in electromagnetism were no exception. However, what Heidegger failed to appreciate was the fundamental novelty of those experiments. The Newtonian system was the product of the Euclidean-Archimedean-Aristotelian abstraction of the six simple machines and Galileo's reduction. The grid that it projected over phenomena was the projection of the abstracted motions of the balance, the wheel, the lever, the wedge, the inclined plane, and the scew: the first machine-family. It projected the balance as the corrective principle of Nature and defined force in terms of the lever. The electromagnetic machines of Oersted, Davy, and Faraday were a novel machine-family. Did they require a novel ground-plan? Was Heidegger too much in the sway of Newton (and Heisenberg, for that matter) and the view that physics is a mathematical science? After all, Faraday is famous for not being trained in the use of mathematics and for being an exemplar of a modern experimental physicist. Was Faraday an exception? Or does Faraday show that physics is not actually mathematical but only uses mathematics as a technique? How did Faraday project his ground plans? In order to answer these questions we need to take a closer look at how Faraday developed representational techniques. Gooding analysed the processes by which Faraday was able to visualise "invisible" phenomena in terms of *construals*.[35]

Construals:

Gooding's argument was that experimenters intervene in "the natural world" and construe their experiences to *create* the correspondence of representations to experience. Observers with different theoretical predilections can agree about salient aspects of the phenomena whilst disagreeing about their theoretical significance. How? Agreement is negotiated by exchanging tentative visual constructs about "the observed" - *construals* - of personal experiences. Observers publicly construe and re-construe their experiences in relation to the construals of other peoples' experiences. Construals are pre-theoretical, practical, situated, and concrete, visually representative means of interpreting novel experience and communicating trial interpretations. For example, when we picture "light" as either "rays" or "waves" we are using construals. They are a tentative and public means of visualising an otherwise "invisible" phenomenon (i.e. the motion of light). Construals permit observers to have common (commensurable) experiences of phenomena. As Gooding noted (1990, p.63), the acts of making novel experiences of novel interventions intelligible, such as Biot, Davy, and Faraday's experiences of the motion of a magnetic needle around an electric wire, need to be ordered in either "real space and time, by moving a real needle around a real disc" or in an imaginary geometrical space. The visual record, in drawings, sketches, and geometrical diagrams, provided the means by which personal experiences could be construed in a form available to public experience. As a form of making spatio-temporal order, construals provided the content of the *ground-plan* projected over the phenomena during the setting-up of further experiments. In the case of the early experiments, this ground-plan was not the motion of points of mass upon a space-time grid but, rather, the construed motion of the tips of magnetic needles, iron filings, and electric wires upon a space-time grid. This was the projection of a new machine-family. It involved the space-time mapping of the *interactions* between moving a needle around a wire and the movement of that needle in response. In my terms, it involved mapping-out the contours of human interventions and machine performances. The construals that were used to map out those contours were circles, tangents, arrows, push-pulls, rectilinear motion, anti-parallel motion, and skew motion. This projected ground-plan was essential for the transformation of a magnetic needle into a technological object. It could become a probe (or a sensor) and its construed motions could be re-described in terms of "sets", "tendencies", "pointing", "dipping", etc.

Gooding observed (1990, p.78-80), in reference to Faraday's notebooks, that Faraday was aware of the problem of recollecting *how* he had construed previous experiences. Faraday devised a tactic to deal with this problem. He invented instructions, techniques, on how to construe his previous construals in such a way as to make those experiences stable and repeatable. For Faraday, construals were the interpretive possibilities of motion. These developed against a background of the regularities that he learned to produce. The construals of motion - as provisional and flexible interpretive possibilities - can be compatible with

[35] Gooding (1990) esp. ch. 5 described how Faraday made circular motion by inventing construals of the performance of the novel needle-wire-magnet machines.

several theories or with none. They enable the earliest (pre-theoretical) stages in the interpretation of novel phenomena and have a heuristic function as a technique for exploring an emergent phenomenal process. As Gooding pointed out (1990, p.116), construals are selected on the basis of their heuristic, communicable, and instrumental value. Construing involves a complex process of relating actions and imagination. It links concrete and abstract space in which both are distinguished, through the construal, in relation to the other. Construals make motion a *techno-phenomenon*. Attention to the use of construals in communicating techniques and experiences highlights the *pictorial* (rather than linguistic) aspect of scientific imagination. The judgements regarding how phenomena should be represented are socio-technical judgements (made in relation to both other people and material practices) regarding the intelligibility of any *techno-phenomena* and how to produce them. As Gooding pointed out (1990, pp.66-7), consensus between experimenters depended upon the successful exchange of observational and manipulative techniques. This involved the dissemination of qualitative and pictorial representations of the phenomenon-as-a-process. In my terms, this involved the dissemination of *techno-phenomena*: it involved the social organisation of a mode of disclosure through technique.

Gooding argued that construals are central to the processes of experimentation and they do not permit either a monolithic fit with articulated theories or a metaphysical commitment to determinism (a.k.a. realism, materialism). I agree with Gooding. However, this raises an important question that Gooding, given the peculiarity of Faraday's lack of mathematical training, did not address: how do construals link with mathematical practices and models?

<u>Technographe and Mathematical Practices:</u>

I use the term *technographe* as a modification of Derrida's term *graphe*. *Graphe* was used by Derrida to denote styles of writing; that specific styles of writing, or inscription, were required for science to be possible.[36] However, Derrida neglects mathematical forms of inscription and these are essential in experimental physics. I shall argue, following Heidegger, that modern physics is inherently mathematical.[37] I term these mathematical forms of inscription as *technographe* because they are a form of physical marks, *graphe*, that are used *technologically* in the design, interpretation, and inscription of machine performativity. *Technographe* are used for writing down mathematical techniques and inscriptions. They are the parts of mathematical writing used in constructing solutions, demonstrating proofs, calibrating mechanisms, modelling the performance of machines, and for designing machines. Geometrical proofs, algebra, analytical differential calculus, vectors, matrices, statistics, etc., are all written down, recorded,

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[36] Cf. Derrida (1967) especially pp. 81-7. Latour & Woolgar (1979) used Derrida's idea of *inscription* to characterise graph plotting machines used in scientific work as *inscription devices*. Like Derrida, Latour & Woolgar treated science as a form of writing for which the aim was to produce text. They neglected to attend to the way that scientific inscriptions are fed-back into the processes of experimentation, as part of technique, in order to produce the inscription devices in the first place.

[37] In both Heidegger's sense of the term and in the common sense of involving mathematics.

printed, and disseminated, through the use of *technographe*. *Technographe* are not the mathematical techniques themselves, in the same way that *graphe* do not tell us how to write or how to read. They obtain their meaning as part of the inscription and interpretation practices used in those mathematical techniques. They are situated within the hermeneutic system of the ordering technologies of those techniques and they require mathematical artifice to be effective. Examples of technographe would be a drawn circle, arabic numerals, an equal sign, a differential operator, vector notation, matrix notion, etc. Feynman diagrams, electric circuit diagrams, and design schematics, are all examples of inscriptions constructed using *technographe*.

Euclid's first proposition, to construct an equilateral triangle by intersecting two circles, in *The Elements* is not a *logical* proof at all.[38] Formally, in terms of modern logic, Euclidean geometry is incomplete because it lacks a continuity axiom in either the Postulates or the Common Notions.[39] The first proposition remains unproven because it has not been demonstrated that the two circles actually intersect. From the perspective of modern logic, the Euclidean geometry available from antiquity to the nineteenth century was not a complete logical system. It was an art rather than a science. The basic postulates of Euclid's geometry, such as to describe a circle with any centre and distance, draw a straight line from any point to any point, etc., are distinct *technographe* that can only acquire their meaning through repetitive practice. These practices are comprised of the inscription acts involved in the mathematical inscription of geometrical figures. In turn, each geometrical figure, once inscribed, becomes a distinct *technographe* that is used to inscribe further geometrical figures. The first proposition is inscribed by performing the technographic acts of drawing straight lines and circles. A straight line and a circle are defined by Euclid in terms of acts of drawing and, consequently, we can only learn how to perform these practices by following instructions, performing the inscriptive act, and being informed that the resultant is correct. Each figure is a socially mediated artifact, a technological object available for further use, and only achieves its truth within the artifice of Euclidean geometry as a set of tacitly embodied practices and their products. We are only able to intuit the indubitability of these products once we have acquired the artifice of Euclidean geometry and have become mathematical practitioners. Once this artifice is acquired, through education, then practices, reasoning, and intuitions are ordered within its framework.

Euclid's geometry is a form of writing in which a set of primitive inscriptive practices constitute the basis of the whole corpus. Proposition 1 provided the *technographe* to inscribe an equilateral triangle. This was used to construct further *technographe*. For example, Proposition 1 was used as a technique in the

[38] This has been widely accepted by mathematicians and logicians since Frege published *Begriffsschift* in 1879.

[39] Aristotle seems to have been aware of this. In *Phys* VI, 1, 231a24ff, he argued that a line does not arise out of points, nor a surface out of lines, nor a volume out of surfaces, because in each case there is something lying in between that cannot be constituted out of the elements in terms of the preceding elements. A determinate kind of connection, a determinate kind of unity in the manifold, is required. Aristotle rejected the applicability of mathematics to the complete description of movement.

construction of Proposition 2 which, in turn, was used in the construction of Proposition 3, and so on. Each use of *technographe* is an *exemplar*, in Kuhn's sense of the word, because it constitutes a set of problem solving tactics that are learned, or constructed, by using them to solve problems.[40] They are *technai* in the pre-socratic sense of the word. These *technai*, as exemplars, were *technographically* used in *The Elements* to construct geometrical treatments of angles, straight lines, ratios, circles, curves, areas, and solids. It is as exemplars that their self-evident correctness is established by being able to use them. Each proposition is proved by the act of inscribing it. Its self-evidence is a resultant of its practice and, consequently, Euclidean geometry is as eternal and universal as the inscription practices upon which it is based. Each axiom is an encodification, abstraction, and reification of a set of inscription practices. Its status as an *episteme* is achieved by its acceptance amongst its practitioners (and anyone else that they can convince) on the basis of claims for its completeness. These *epistemoi* are collected together and integrated within a technical system as a fixed "technological framework" with a specified object-sphere (the geometrical figures, proofs, and theorems) and a well defined set of interpretations as to how to combine and relate them. Euclidean geometry is characteristic of a *techne*, from the platonic usage, and an *episteme*, in a Foucaultean sense of the word, as being a total set of related inscriptive practices that is socially presented as eternally, universally, and necessarily true scientific knowledge.[41] They are discursively and technographically related via their embodiment in practice during education. In this sense, Euclidean geometry is an enduring *techne* that has been discursively presented as an eternal *episteme*. *The Elements* provided the *technographic exemplar* for the works of Archimedes, Apollonius of Perga, Nicomachus of Gerasa, and many others. This can be seen in the geometrical proofs of Archimedes and Apollonius, and Nicomachus' study of arithmetic based upon Euclidean ratios.[42] These works, as well as *The Elements*, were preserved and disseminated from antiquity, through the medieval period, and into the present day. The structures of these geometrical treatments were organised within the Euclidean template of axioms, postulates, propositions, corollaries, theorems, and proofs; they provided the exemplars for all subsequent geometry to emulate. Archimedes, Apollonius and Nicomachus innovated new *technographe* and extended the Euclidean *techne* to include irrational numbers, projections, powers, series, and the geometry of ellipses, hyperbola, and parabolas.[43] The role these *technographe* had in the construction of mechanics cannot be overstated. The science of mechanics and the *techneic* use of *technographe* to inscribe the motion of the

[40] Cf. "Postscript" in the second edition (1970) of Kuhn (1962).

[41] Foucault (1961/1994) used the word *episteme*, in his analysis of the mutation of organised knowledge from the Medieval to the present day, to characterise distinct strata of the ordering of discursive practices within texts of given eras.

[42] Cf. Heath (1949)

[43] Both Archimedes and Apollonius developed and used their mechanical methods to begin developments of infinitesimal calculus. However, Euclidean *technai* and *technographe* proved cumbersome for this task. This had to wait until the seventeenth century construction of new *technographe* that analytical geometry and calculus, for example, could be constructed as a set of exemplars to solve a wider range of problems.

simple machines were one and the same thing. As I argued in the last chapter, it was the conflation of Euclidean geometry as a *techne* and *episteme* (in the context of the construction of the mathematical science of mechanics and the European desire for novel technological powers) that lead to the emergence of mechanical realist metaphysics, the possibility of experimental physics, and the conception of modern scientific technology.

The axioms of geometry have application in our world of experience because, through artifice, we have mathematically projected that application onto parts of the world. It is through the embodied *praktognosia*[44] of pre-conscious habitual familiarity with the techniques of geometry that we are able to "intuit" the applicability of this projection. These axioms encodify the structure that we impose upon parts of the world. This is not a structure of our untrained consciousness; it is the structure of the imposition itself. It is the structure of the mathematical inscriptive practices of the artifice of geometry. If *techne* resides "in the soul of the craftsman" it has been inscribed upon that "soul" through training, mimicry, and practice. The "soul of the craftsman" is not something that we are born with. It is something that we learn and embody through the social acquisition of technique to the extent that we become so familiar with its practices that we are no longer aware of them. Our educated bodies have become situated within the "technological framework" of geometrical inscriptive practices; that framework, once embodied, becomes part of us. The art and the artist reside in the same place. Projecting the trained imagination performs the "outer sense" of mathematical projection. Our ability to have *a priori* knowledge of the truth of the axioms of geometry is dependent upon the invisibility of technique itself. Our capacity to ground geometrical imagination in self-reflective knowledge is itself a manifestation of the pre-consciousness of technique to a being that is already well versed in the application of that technique. If the technique is invisible then all we see is the projection. It was for that reason that Kant located the origin of that projection in the structures of pure intuition rather than in the art of geometry itself. He was sufficiently skilled in the art of geometry to the point where the art became invisible and its practice became innate.

The mathematicians' demand for formal rigor is always the demand for the formal rigorisation of non-formal practice. It is the demand for the logical encodification of abstracted and reified skilled human labour. However, the formal axioms, the logically abstracted and encoded system, will be both unintelligible and useless without the skilled practices from which it was reified. A logical proof for the constancy of the ratio of a circle's circumference to its diameter is meaningless if we are unable to draw and recognise a circle. It will not do to appeal to pure conceptualisations of a circle either because without the skilled practices from which those conceptualisations were abstracted there would be absolutely no possibility of applying them in the world. Application requires practice. The *technographic* practices of geometry (drawing using a straight edge and a compass) were reified in response to the degree of

[44] Maurice Merleau-Ponty (1999) to capture the primacy of tacit and practical knowledge used the term praktognosia. It has parallels with Michel Polanyi's (1958) tacit knowledge except that, for Polanyi, tacit knowledge was situated in the educated intellect whereas, for Merleau-Ponty, this knowledge was embodied in the situated and habitual motility of the existential body-subject.

unreflective application of those practices. This reification was itself the product of the challenge of imposing "rational order" upon practices which were both informal (lacking in rigor) and disordered (inconsistent). The abstraction of those practices was an encodified simplification of what was already taken for granted as being technically correct, in such a way as to induce a universal *techne* under which those practices would be integrated under a single theory of practice, which paid no attention to the particularities of practice. The move towards abstraction is an attempt to detach the technique from its application in order to generalise it from the particularities of use. This involves a synthesis of a diverse and divergent set of particularities into a general encodification that can be applied equally to all those particularities. Under the *techne* of geometry the objects produced by the application of that *techne* would be abstract, idealised reconstructions of *technographe* that were conceptualised in terms of definitions generalised as axiomatic principles. This reification allowed the axioms of geometry to be divorced from their practical origins and contexts of use. However, this abstraction itself required the techniques (and practices) of logical encodification into general rules which, in turn, also requires abstraction if the formal system is to be a complete *techne*. That process will also require technique. And so on....

All mathematical abstractions, as encoded reifications of techniques, are incomplete. This is the source of all error and problems for the application of a formal system to experience. It is not the case that the formal system does not correspond to reality (as the realist would argue) and hence the error. It is more the case that the system is itself incomplete and we are not in possession of a full and complete *techne*. In short, we do not know what it is that we have done, nor do we fully know how to apply the general system to particular experiences. We are forced to keep experimenting or give up. Furthermore, without completeness we are unable to unify the whole abstraction into a formal *techne* and, consequently, we cannot consider the particular practices from which the system is abstracted to be homogeneous. They are a heterogeneous collection of exemplars and tactics. It is this heterogeneity which is the source of all "error" and "resistance". This is a matter of coherence rather than correspondence. The challenge of system building is to collect together and integrate heterogeneous objects into an homogeneous whole. The inconsistencies that arise during that process are the results of the interference between heterogeneous objects, which were not designed to be integrated in those particular ways. The "failure" of any system is a consequence of its incompleteness, complexity, and disunity.

The invention of non-Euclidean geometries brought with it a novel awareness. Not only were geometrical objects the products of our mathematical practices but they were also arbitrary. There is nothing unique about any particular set of *technographic* practices; dimensionality can be projected in any number of different ways. Any numbers of new technographic practices were possible (as Boltzmann, Lorentz, Minkowski, Gauss, and Einstein have shown). We are free to construct any topology from any arbitrary set of axioms. That topology is considered rigorous, in the disciplinarian sense of the word, providing that our axioms and definitions do not contradict one another when we attempt to combine them. There is not any "objective" space to which mathematical geometries must "correspond"; topology can only provide us with an encodified system of consistently mapping arbitrarily imposed axioms and definitions.

The problem is how to relate these arbitrary spaces to the practices of experimentation and measurement. Once again, this raises the question: How is the "empirical" practical dimension of experimentation connected with the "rational" mathematical dimension? The case of Faraday's work provides an illuminating answer to this question. If we accept Gooding's argument that the use of construals was central to Faraday's public reasoning process then we can readily see that this process was a *technographic* process. Socio-technical judgements are premised upon *technographic* cognitions and it is for this reason that I agree with both Gooding and Heidegger. Such cognitions are made within the context of a socio-technical learning process and realised "for ourselves" as something brought by us to the learning experience. This is not an innate cognition but is a socio-technical cognition that is made "ours" through the embodiment of artifice through innovative practices. It is premised upon an open and praktognosic orientation towards objects from within the invisible "technological framework" of embodied artifice. Thus Faraday's work was not mathematical in the common sense of using mathematics, but it was mathematical in Heidegger's sense of *mathesis.* As Gooding pointed out (1990, p.87), "[s]uccessful construing creates 'giveness' of experience... [it is] a relatively stable but plastic interpretation of experience which guides further exploration and interpretation." It is this 'givenness' that is characteristic of *mathesis* and mathematical projection. It is the "laying down of the ground-plan of Nature" *in retrospect* whilst leaving it open for future refinement.

Ampere's key experiments, as Gooding noted (1990, p.46-7), involved preventing movement. His experiments were designed to reduce complex interactions to just one of the possible configurations: stable equilibrium. Why did he choose this particular configuration? There are two possible reasons that I would like to discuss. The first possibility was that Ampere had adopted a mathematical tactic, in the common sense. This tactic was set-up to avoid the practically unachievable task of finding solutions to the mathematical expressions for the complex phenomena produced by the "process-structuring" techniques of Oersted, Davy, and Faraday. In my view, this tactic was the attempted extension of the Galilean reductive method of reducing all mechanical motion to that of the lever and the balance. This would have allowed Ampere to treat the problem as if it were one of ratios and simple differentials. The second possibility was that Ampere had adopted a mathematical tactic, in Heidegger's sense. He projected the Galilean template. Faraday, on the other hand, was destined to non-mathematical work, in the common sense.[45] And yet, in Heidegger's sense, Faraday was an exemplar of mathematical projection. How did Faraday know how to begin? From Newton? According to Gooding, Faraday's plans of action began in October 1820 with attempting to reproduce and map out the contours of Oersted's famous needle-wire motion observation. After eleven months of experimenting with sideways motion, circular motion, and push-pulls, he managed to stabilise his configuration of the 1821 compact rotation apparatus. This produced revolutions. It was the stable predecessor of the electric motor. It was a hybrid electrical and magnetic machine that produced stable rotations when it was connected to a chemical battery by metal wires. It both enabled and constrained the spontaneous circular motion of a needle pendulum around a magnet. Yet this kind of motion had been

[45] This would put him in the "empirical tradition", according to Kuhn and Osler.

seen before. These are the primary motions of Newton's mechanics and the totality of Galileo's. I shall put aside the question of what enabled such motion until chapter six. For now, what constrained that motion? As Gooding observed, the motion of a suspended magnetic needle around an electric wire is far from stable and well defined. It takes considerable patience, practice, and skill to manoeuvre a needle around the wire (without it touching the wire) and map out its motions. One must control one's interventions carefully. How did Faraday plan the control of his interventions? He did so by exploring the possible motions of sideways motion, circular motion, and push-pulls, and with meticulous attention to those possibilities, Faraday mapped out the contours. The 1821 machine was designed to demonstrate circular motion and an otherwise quite unpredictable movement was constrained to a circular path. It is in this sense that Faraday mathematically projected, in Heidegger's sense, the six simple machines as the possibly stabile motions to try. Faraday's experiments on the motion of magnetic needles and electric wires were constructed to capture the circularity of that motion. By doing so, Faraday projected the ground-plan of circular motion. However, as Gooding pointed out, Faraday's "rotations" - his screw-construals - were a non-newtonian construal of force.[46] He deconstructed (via Ampere) the applicability of Galilean reduction to the novel electromagnetic machines. The screw was a non-reductive exemplar of "electromagnetic motion". And it was still one of the simple machines. He managed to resolve his difficulties in construing that motion by using the screw as his construal. Maxwell's field theory utilised Faraday's construals of the tangential, or skew, motions of "electromagnetic lines of force" in terms of the screw. Faraday's construal of his experiences in terms of screw motion of the "invisible" lines of force is a breaking free from the Galilean reduction. The mechanical circular and rectilinear motion would not suffice for the novel machines. Faraday's screw-construal was a non-reducible primitive.[47] Once the *grad* and *curl* operators of differential calculus had been invented by Maxwell (and specifically invented for this task) then such motion could be described in terms of differential calculus. How? So far, I have only discussed the pictorial and geometrical *technographic* inscription of machine performances. One of the crucial mathematical innovations of the seventeenth century was analytical geometry and differential calculus. These allow machines to be analytically inscribed. How are machines and analytical differential calculus connected? Furthermore, how do *technographic* inscriptive practices connect with modelling? How do *technographe* represent *techno-phenomena*? In order to answer these questions, I need to introduce Gilles Deleuze and Felix Guattari's idea of *functives* and *exoframing*.

Functives and Exoframing:

Functive was a term used by Deleuze and Guattari in their analysis of science and its distinction from art

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[46] It is also arguable that his field-lines pre-empted the non-euclidean spaces of Einstein *et al.*

[47] Gooding noted (1990, p.117) that "Faraday took up the possibility that the skew-aspect was not to be reduced." For an example of Faraday's construal of "skew" motion see Thomas Martin's transcription of the first part of Faraday's experimental record for 3rd. September 1821 (reproduced in Gooding 1990, pp. 122-3). Here we can see Faraday construing such motions as a screw.

and philosophy.[48] A functive is an element of a function. Limits and variables are examples of functives. A function defines the relationship between its functives and may, in turn, be used as a functive within another function. In physics, a function has to refer to a co-ordinate system in which the axes represent physical quantities. In Deleuze's terms, physics proceeds in the face of the infinite chaos of existence by constructing a plane of reference from co-ordinate systems in order to slow down the disorder of chaos by external framing (or *exoframing*). Exoframing involves extrinsic determination of the meaning of the frame of reference. Physics is distinct from mathematics due to this extrinsic determination. The latter finds its meaning in the intrinsic and interpreted relationships between functives whereas the former has to extrinsically give those functives physical meaning. Exoframing allows functives to participate in modelling. It is exoframing that provides a co-ordinate system composed of a least two independent functives, whose relationship is the function, with meaning as a state of affairs or informed matter. Exoframing is necessary for the frame of reference to form a proposition that relates a state of affairs meaningfully to the system in question. For example, it is the act of exoframing that is required for the differential functive dy/dx to refer to the rate of change of pressure with respect to temperature and to have meaning as a state of affairs between pressure and temperature in a system that is extrinsically determined as a sphere of gas at constant volume. The function allows each dimension (axis, variable) to be fixed whilst the others are varied. Exoframing allows mathematics to participate in modelling machine performances.

Functives and technographe are meaningless without the enframent of inscriptive practices and hermeneutic relations in which they are situated. This enframent, itself a part of artifice, is a mathematical method (a procedural collection of mathematical techniques). It will utilise techniques and ordering technologies as part of that method(s). This method is associated with its application. For example, Fourier analysis involves a collection of different technographe, functions, functives, techniques, and inscriptive practices. It is technique for analysing complex "wave patterns" in terms of series of sine and cosine functions. In order to be effective it must be embodied in inscriptive and hermeneutic practices, as a part of artifice, in the context of solving a range of particular problems. By applying Fourier analysis to the solution of an inscribed physical problem, say the solution to the Schroedinger Equation for electrons within a metal wire under a potential difference V, the solutions of this technique can be exoframed as expressions of physical states. The sine and cosine functions of the Fourier series can be taken to be the wavefunctions that are superimposed to probabilistically describe the measurable behaviour of the electrons.

By inscribing the contours of the interactions between human interventions and machine performances, in terms of functives by using technographe, the contours can be mapped out in terms of operational and responsive variations. The physicist can slowly turn up the pressure acting on an experimental cell and read the variations in temperature from a calibrated thermometer. This can be recorded graphically and written down in the form of a differential equation. Differentials are particularly

[48] Deleuze and Guattari (1994) esp. chap. 5.

suited for inscribing machines and mechanisms. The differential relates variables in terms of a ratio of a rate of change, of one with respect to another. These variables can be used as dimensions to construct an analytical "space" in which the differential equation can provide the "contours" of the physical process under investigation in terms of an exoframe that can be projected over the machine performativity in terms of fundamental variations and dimensions. It will already be apparent how the process of exoframing, the construction of an external frame of reference between variables, already facilitates the process of writing out, de-inscribing, both human interventions and machine performativity from the final products of experimental work. The technographic inscriptions can then be taken to be *representations* of the physical processes involved in the experiment. Both human interventions and machine performances are de-inscribed (written out) from the final accounts. The book of Nature can then be read. However, before discussing how this process of de-inscription is achieved we need to examine how exoframing relates to the ongoing activity of "making" the ground-plan of Nature.

"Making" the Ground-Plan of Nature:

The work of Faraday was an example of mathematical projection, in Heidegger's sense. He projected the six simple machines over the novel phenomena. Faraday also modified the ground-plan to allow himself more freedom to construe the screw motion without the restriction of the Galilean reduction. Faraday *et al.* had invented a novel machine-family and confirmed the methodology of mathematical projection. His work is an example of how the so-called "rationalist" and "empiricist" traditions were both aspects of the same "technological framework". It was this "technological framework" that Heidegger (1977b) termed as methodology. He characterised methodology as the second essential characteristic after mathematical projection. According to Heidegger, methodology sets in place an object-sphere and procedure in which rules and laws of change can be determined and questioned. In my view, Faraday was an exemplar of this. He projected his ground-plan of action in order to establish a series of interventions by which he could map out the phenomena by building machines. He did this by projecting the ground-plan of the six simple machines and constructed ensembles that could produce the motions for the template. This provided Faraday with a general methodology by which he could set in place his object-sphere (his magnets, wires, needles, etc.), his set of possible construals (rotations, screws, antiparallels, etc.), and his procedure (build a machine and map out its motions). The rules and laws could then be abstracted from the technographic maps of the motion of the machine. According to Heidegger, procedure must set in place the changeable and allow it to change, as its object, in order to allow facts to become objective, fixed, and, hence, determinations of the constantness of the changing of the changeable can be made into rules. Again Faraday did this. By building these novel machines, Faraday transformed the movements of magnets and needles into the changeable motions of the six simple machines. He did this by constructing the apparatus in such a way as to prevent it from making any movement that was not a simple machine motion. I am not claiming that Faraday was a stage magician who built a trick. What I am claiming is that he reduced the possible movements to that of one of the six simples. His procedure, building a machine according to the template, set in place and restricted the changeable movement to one of the six projected mechanical motions, in such a way as to make it repeatable within the projected plan. This allowed the technographic construals and representations of that motion to be used map out the contours of that motion in terms of constants and variables. These can be used to construct an exoframe and, eventually, a mathematical law.[49]

What is this "changing of the changeable"? It is machine performance. Methodology sets down the set of techniques and technological objects that will be used by the research to disclose the "natural mechanisms" to be realised by that experimental research. The process of research is then one of mapping out the contours of the interaction between human interventions and machine performances by using those techniques and technological objects as transformative agents. It is the task of the experimenter to determine, in relation to the contours, which aspects of machine performance change in response to particular human interventions. These aspects are "the changeable". The process of research is subsequently one of mapping out, as a result of the interactions between human interventions and machine performativity, the changes of the changeable in response to those interventions. For example, we could map out the change in volume of a gas in relation to changes in pressure and temperature. This would involve collecting together the technological objects, say a piston, a bunsen burner, a thermometer, and a pressure gauge, and then by varying each of the variables (temperature, pressure, volume) in relation to one of the others (whilst the third is fixed) we could map out the contours of human interventions and machine performances. Those contours could then be presented as the manifestation (resultant, consequence) of the realisation of the rules by which those variables are related "in Nature" via a mechanism. By inscribing those contours in terms of an exoframe we could then write down the differential equation for those rules. What we have done (or so the mechanical realist would claim) is to create an artificial space (free of the chaos of competing mechanisms) by which those rules could be disclosed. Furthermore, or so the mechanical realist would claim, the differential equations that we have written down are, in fact, a representation of the "laws of Nature" that govern such a process. It is for this reason, on my reading, that Heidegger maintained that, by fixing these rules as the necessary consequences of natural laws, methodology is able to determine the laws of Nature in terms of the rules governing the changing of the changeable that has been set in place by procedure. By projecting the ground-plan of Nature, physics has made this so. Facts can only be made clear, as the facts, within the purview of rules and laws, and, therefore, research into the facts is intrinsically the establishing, verifying or falsifying, rules and laws. In my terms, physics is thus able to perform the "sleight of hand" that has been premised by the pursuit since its origins. Through methodology it engages in a process of making that is directed towards the *techneic* realisation of unchanging principles of change. It has presumed, on the basis of mechanical realism, that these principles are *epistemic* principles, whilst simultaneously de-inscribing the participation of human interventions and machine performances from that process. It is then able to remove its own methodology (using machines, etc.) from the final account and present its *techne* as "Natural Law".

[49] The empircist will then claim that the law is a good fit to the phenomenon, and the rationalist will then claim that it is a necessary consequence of that law.

For Heidegger (1977b, p.120), the projected object-sphere is made objective by encountering it in "the complete diversity of its levels and interweavings" in order that procedure is freely directed to view the changeableness in its object-sphere that provides "the horizon of incessant-otherness of change" required for facts, as concrete particularities, to become present. This is crucial. For Heidegger, human beings do not control the outcome of experimentation. The disclosed would not have been disclosed without human intervention but the disclosed is not controlled by that intervention. What is controlled is the template of the experiment, how it is performed, and this template constrains what can be learnt. This provides methodology with an explanatory character because it can present itself as a mode of disclosure. Methodology accounts for an unknown by means of a known and, at the same time, verifies that known by means of that unknown. Both knowns and unknowns are used to explain each other. Heidegger did not provide an example of this. A good example is the case of gravitation. Newton's Law of Universal Gravitation explained already established facts (objects fall to the ground when dropped, the Moon orbits the Earth, and the planets orbit the Sun in elliptical paths) in terms of an unknown (the unitary force of gravitation) via a procedure (the calculation of paths using the inverse square law). Hence the unknown could be accounted for in terms of the known facts and these facts were verified as necessary consequences of the unknown. This can also be seen in Faraday's experiments. The known possible motions of electromagnetic machines would be explained in terms of "an unknown force" via a procedure of mapping out "the lines of force".

In modern physics research takes place by means of experiment. The ways in which experimentation is performed is dependent upon the particularities of what is being investigated and which type of explanation is required. However, it is only through the transformation in general conceptions of knowledge and Nature that research through experiments became possible. What was this transformation? Firstly, mathematical projection, as discussed in the last chapter, is a condition for research through experimentation. It is this condition that distinguished modern science from medieval *scientia* and ancient *episteme*. Aristotle's understanding of *emperia* as the attendance to the phenomena, their qualities and movements under changing conditions, in order to achieve knowledge of the tendencies of things, was *essentially* different from the modern scientific observations made through experimental research. Even when ancient and medieval studies worked with number and measure, using instruments and apparatus, the character of observation was essentially different because they lacked the decisive characteristic of modern experimentation which, according to Heidegger (1977b, pp.121-3), begins with laying down a law as a basis. This may, at first glance seem a surprisingly Kantian move. However, Heidegger was concerned with the metaphysical projection implicit to modern physics. An experiment does not begin with a complete physical law, which it then tests (as if often presumed) but it does presuppose the existence of a law, which it aims to disclose. Thus, as Bhaskar argued, the presumption of the existence of a law is the basis for an experiment. As Gooding argued, the "discovery" of this law, in the form of an empirical regularity or a form mathematical abstraction, requires considerable effort on the part of experimenters and may take decades of work before it has been formulated. However, on my reading, Heidegger was setting-up the methodology by which experimental physics operates. This does involve the presumption that there is a law, which can be disclosed by the proposed experiment (or series of experiments). It also presupposes the forms of possible motions that would qualify as regular motions. As I have argued above, these motion were the motions of the six simple machines for both mechanics and electromagnetism. For Heidegger, to set up an experiment requires representations and conceptions of the conditions under which a specific series of motions can be made susceptible to being "controlled in advance by calculation" and followed in its "necessary progression". On my reading, Heidegger was directing us to the way that physics has pre-empted what could be possibly learnt, to such an extent that it has pre-empted the conceptual and representational conditions under which an empirical regularity would be produced and recognised, and accepted as such, and these representational and conceptual conditions also pre-empt how the experiment could be built in such a way as to be a controlled experiment. In other words, it has pre-empted what qualifies as a constant conjunction and the conditions under which an experimentalist could claim to have produced constant conjunctions. It is because a constant conjunction is a repeatable conjunction of events, and each event is construed, in advance, as one of the projected six simple mechanical motions, then performing an experiment *inherently and necessarily* involves constructing machine performance. The experiment is controlled to the extent that some kind of machine performance will be its consequent but which combination of simples will be disclosed is not controlled. This allows physics to participate in discovery. It discovers the particularities of the machine performance of the machines it has built according to the preconception of how a machine should perform. It is for this reason that I agree with Heidegger's claim that Natural law is established with reference to the ground plan of the object-sphere that provides criteria and constraints upon the anticipatory representation of the conditions under which the experiment can be performed. This set up is required to prevent the representations necessary for experiments from being based upon "random imaginings". The set up is based upon the ground plan projected onto Nature and the representations are sketched into that ground plan. The planning and execution of experimentation, as a methodology, is supported and guided on the basis of the fundamental law that allows the facts, that either verify or falsify the law, to be adduced. In my terms, the character of this fundamental law was presumed to be techneic from the onset, the possibilities of experience were constrained by the projected template of the six simple motions, the required combination of simples were mechanised. The experiences acquired during that process of assembly were induced into a general techneic form. Due to the operational precepts of mechanical realism this *techne* was conceivable as the holy grail of "Natural Law". Heidegger maintained that modern experimental research provides observations that are more precise (in degree and scope) and is methodologically essentially different in kind than medieval *scientia* and ancient *episteme*. It is the way that modern experimental research is related to, and at the service of, the verification and falsification of law in the *framework* of an exact plan projected onto Nature, as the ground-plan, that provides the essential characteristic of modern experimental science.

The next stage in Heidegger's analysis was to examine specialisation as an essential characteristic of the ongoing activity of modern science (1977b, p-p.123-5). For Heidegger, every science, as research, is grounded upon the projection of a circumscribed object-sphere and is itself circumscribed as a distinct science on the basis of the distinctness of its object-sphere. In my view, it is technique that binds together an object with procedure and methodology; hence the "technological framework" of techniques and objects upon which it projects its template defines the methodology of any experimental science. Distinct sciences are defined in terms of distinct sets of techniques and technological objects. The objects of all experimental sciences are technological objects because they are constrained to be disclosed, and to disclose other technological objects, only to the extent that they are disclosed by technique. This is as true for rats in biological experiments as it is for the motion of needles around wires. Rats are disclosed by technique to be a set of machine performances (repeatable responses to interventions) just as much as the needle and wire were when Faraday assembled them into a rotation device. Each machine is associated cluster of techniques, technographe, exoframes, and technological objects, is a distinct object-sphere. The exploration of that object-sphere in "the complete diversity of its levels and interweavings", by mapping out the possible interactions between human interventions and machine performances, is an experimental research project. For Heidegger, each science, in the development of its projected plan by means of its methodology, is particularised into specific fields of investigation. For Heidegger, the particularisation (specialisation) of each science into specific fields of investigation was not a "necessary evil", due to the increasing unsurveyability of the results of research, but was an essential characteristic of science as research. Specialisation was the foundational condition for the progress of all research. Why? For Heidegger, specialisation is a necessary consequence of the third fundamental event of modern science. Heidegger identified this third fundamental event as "ongoing activity".[50]

Heidegger highlighted that practical activity was an essential characteristic of modern research. Any attempts to disown it (by characterising science solely as "serene erudition") could not sustain a notion of modern science as an ongoing activity, nor its performativity, nor its capacity for enduring, nor the "self-evidence" of its results (1977b, p.138). Ongoing activity, in order for a science to be respected as a science, provides modern science with the capacity for institutionalisation. Each institution is defined in terms of its

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[50] Lovitt noted a translation difficulty in rendering *Betrieb* as "ongoing activity" (1977b, p.124 fn. 10). He noted that *Betrieb* means the act of driving on, or industry, activity, as well as undertaking, pursuit, business, and can also mean management, or workshop, or factory. Heidegger qualified his use of *Betrieb* (Cf. 1977b Appendix 2, pp.138-9) as not intending any pejorative sense. He stated that he intended this word to convey and highlight that the industriousness of research only degenerates into "mere busyness" when, in the pursuing of its methodology, it closes itself from accomplishing novel projections of the ground-plan and, instead, takes that plan as given and simply accumulates results and calculations. (There is a parallel between Heidegger's use of *Betrieb* and Kuhn's use of the term "normal science".) Heidegger argued that "mere busyness" in scientific research was a consequence of the tendency of research to become completely dominated by industriousness rather than remain open to the ground-plan that "gives the impression of a higher reality behind which the burrowing activity proper to research work is accomplished".

self-appointed task: To investigate a particular field of investigation. The methodology through which individual object-spheres are "conquered" does not simply amass results, but, uses those results to adapt itself to a new procedure. It is the adaptation of research to its own results that, as an ongoing activity, provides modern sciences with advancing methodologies and an intrinsic basis for the necessity of the institutionalisation of research. Heidegger's position, that adaptation to new procedures circumscribes the methodology of science by means of its results, is correct, but he left the questions of how this is done, and how methodology opens up new possibilities, unaddressed. How does methodology use results to adapt itself to new procedures? How do new procedures arise? These questions suggest that Heidegger left a "gap" in his analysis of research. I shall discuss the reasons for this "gap" in Heidegger's analysis below and these questions will be addressed in the next two chapters. For Heidegger, the sciences are able to create "the solidarity and unity appropriate to them" upon the foundation of their character as ongoing activity. According to Heidegger (1977b, p.126), planning provides the basis for solidarity of procedure and attitude, with respect to the objectification of Nature that constitutes "the real system of science". The ongoing activity of research builds the plan of an object-sphere into all adjustments that facilitate any plannable conjoining of types of methodology, that further the reciprocal checking and communication of results, and that regulate the exchange of talents and skills.[51] Extending and consolidating the institutional character of the sciences, as an ongoing activity, secures the precedence of methodology over Nature and determines, at any given time, what is taken to be objective in research.[52] The researcher is directed according to research projects that are legitimated by the institution appropriate to the object-sphere in question. The negotiations at meetings, the information collected at conferences, the books and papers contracted by publishers, are all directed and organised through the institutionalisation of modern sciences. The research worker is, consequently, forced to operate within "the sphere characteristic of the technologist" in order to be "capable of acting effectively".[53]

It is *techne* that provides an asymptotic link between practice, theory, and scientific rationality (as ideals). Thus the process of scientific progress is one of aspirations towards technical excellence which is to be achieved via a *techneic* process of questioning and correcting both the content of theories, experimental and theoretical practices, and standards of justification. Gooding termed this process to be one of convergence. This open ended process is one which is perpetually directed towards the future and, as such, is one for which there are not any rules to guide it because we cannot foresee the course of innovative development. It is one of bounded and evolving technical rationality. Controversies regarding the artificiality of the results of techniques and preparations (what is a property of the object and what is a product of the preparation process) could only be achieved by reaching theoretical agreement as a

[51] Hacking (1983); Gooding (1990); Knorr-Cetina (1981); and Collins (1985) made this point.

[52] Cf. Kuhn (1977), Latour & Woolgar (1979), Knorr-Cetina (1981) for discussions of the institutional character of scientific research and the paradigmatic consensus of judgements of what is to be researched and how it is to be researched.

[53] A parallel with Ellul (1965).

consequence of further technical exploration. This requires both theoretical accounts of the techniques utilised and of the object under investigation. The establishment of a *techne* of investigation is the technically rational conclusion of any controversy. Knowledge becomes objective upon the creative establishment of a *techne* of how that knowledge was produced. This involves the abstraction and reification of labour. In this respect experimental physics is something of a conundrum for a Marxist analysis because it is both an exemplar of free-creative labour and the ultimate in alienation from the products of labour.

Prior to publication, any experimenter needs to reflect upon the experiment (its purpose and execution) and anticipate any criticisms to her/his work. Every experiment is situated within the background of a wider scientific community's standards and expectations in which it will achieve its significance and meaning. The working scientist will base her/his conception of what makes a reliable observation and/or technique upon recognition of the level and content of any possible criticisms that her/his work may be subjected to. For Gooding, it was this ability of the experimenter to view for her/himself how her/his actions and reasoning will be viewed by others which was a necessary condition for the critical self-reflection required for "objectivity". In proposing any novel theory or experimental technique it is necessary for the experimenters to break the accepted norms and standards of the current scientific community by engaging in a critically motivated reflection upon the correctness (or legitimacy) of those accepted norms and standards. This requires that the framework that the experimenters are working within is open and capable of being developed and changed. If the framework were fixed, final, and closed there would not be any potential for novel research because there would not be any possibility of establishing new techniques, theories, and objects for investigation. Experimental work is an unending process of producing a series of refinements for which successive refinements correct and reveal the errors of previous efforts. This process is perpetually one in which the experimenters must make judgements between technical frameworks from which to proceed against a background of past efforts and frameworks. Thus experimental science must be an on-going activity that is constantly open to change.

CHAPTER FOUR

THE ART OF EXPERIMENTAL PHYSICS

"Man is a shrewd inventor, and is ever taking the hint of a new machine from his own structure, adapting some secret of his own anatomy in iron, wood, and leather, to some required function of the work of the world." Emerson (1860, p.169)

"For to make use of his hands, no longer to have paws, is to manipulate — and what hands manipulate are tools and instruments. The hand is that hand only insofar as it allows access to art, to artifice, and to *tekhnê*." (Steigler, 1998, p.113)

In the previous two chapters I have discussed how the ground-plan of Nature is made and projected. In this chapter I shall describe how physics is perpetuated and extended. I shall discuss how technological objects for the purpose of investigating Nature are made and used to produce two things: (i) intelligible models of natural phenomena, and (ii) the ongoing development and extension of physics towards its own perfection as a *techne*. Implicit in the concept of experimental investigation is the mechanical realist underpinning of the reality of those technological objects based upon their instrumentality in material practice. Thus Hacking (1983) was a realist about electrons when physicists claimed to spray them on mobidium spheres as part of the process of investigating the existence or inexistence of free quarks. The presumption of mechanical realism allows the production of technological objects to be presented as a fundamental relation between human intervention and natural processes that discloses natural laws by designing, constructing, inscribing, and interpreting machine performances. In this chapter I shall address the question of how Natural Laws and models are connected. I will also address the question of how mechanisms and machines are connected. Mechanisms perform a central function in Bhaskar's (1975) realist interpretation of experimental physics; he required the notion of a mechanism to connect events in closed and open systems by the same laws. The innovation of novel machine-families is taken by scientific realists such as Bhaskar to be a "deeper" exploration, disclosure, and discovery of natural mechanisms, causes, and laws. Later innovations are used to demonstrate (rhetorically and poetically) the existence of a mechanism transdicted to correct the deviation of the performance of a previous generation machine from the on-going expectations of experimentalists. It is for this reason that Bhaskar considers the explanations, the causal-accounts, of the fundamental mechanisms discovered by such an exploration to be an example of "ontological depth". However, in this chapter I shall begin an alternative interpretation of the phenomenon of technological innovation in experimental physics. I will describe how *Ge-stell* (as discussed in chapter two) operates in experimental physics. I shall then compare this operation with Heidegger's definition of *techne* and argue that modern experimental physics satisfies both aspects of Heidegger's analysis of making: craft and modern technology. The convergence operation of *Ge-stell* upon machines provides technological objects with transfactuality by gathering and ordering them into strata of machine-kinds; the innovative extension of technological objects into novel machine-families provides experimental physics with stratification. These provide both of Bhaskar's ontological dimensions. The transfactuality and stratification of the technological objects utilised in experiments provides physicists with senses of ontological "depth" and discovery through the process of making innovation intelligible in terms of models. The labour processes involved in the construction of stability and the convergence of practices towards objectivity, in the artificial contexts of experimentation within closed systems, are nothing more nor less than the construction of repetitions that can be described technographically and presented as empirical regularities. The physicist is discovering how to make making intelligible in terms of the interconnected strata of machines and transfactual technological objects upon which the experiment has set upon. Once mechanical realism has been presumed then techneic causal accounts, operating with technographic functives and visual representations, can be metaphorically used as mechanical models of the natural phenomena under investigation. This is essentially a process of "reverse engineering" in which the physicists construct a mechanistic model of the machine performances in order to imagine the "natural machine", in operation behind appearances, that generates the artificial machine performance. The physicists then compare the expected performance with the actual performance. By invoking the natural economy of mechanisms, when similarity increases, the physicists become increasingly confident that the precepts of mechanical realism underwrite the removal of technological processes from the final accounts. This permits machine performance to be treated as a transparent mode of disclosure, and, the techneic account of the causal series stabilised during the production of empirical regularities can then be presented as the ontological law that was disclosed by the experiment. This metaphysical foundation allows *techne* to be presented as *episteme*, provides experimental physics with an ontological dimension, and the achievement of stability facilitates the abstraction and reification of *techne* as natural law. This chapter will present a further discussion of the social and technological processes involved in the production of techneic accounts. Experimental physics is a labour process that uses models and metaphors in order to produce intelligible accounts of natural phenomena in terms of mechanisms and laws. It uses technological objects to produce further technological objects to satisfy the "internal" challenges of scientific research and the "external" challenges of the wider world of economic, political, and military ambitions. I shall argue that the craft practices and technological trajectories of experimental physics are directed towards the production of intelligible mechanistic models and prototype technologies, and, that the pursuit of modern experimental physics is a mode of both *Ge-stell* and *poiesis* that participates in "world-making".

The On-going Experimental Labour Process:

Any new Ph.D. student entering a modern experimental physics laboratory for the first time enters a highly complicated technological environment populated by already established practitioners.[1] S/he is a novice

[1] This view is based partly on my own experience as a physics student entering the High Energy Physics Data Analysis Laboratory at Lancaster University Physics Dept., and the DELPHI detector site at CERN,

despite her/his (in all but exceptional cases) at least 21 years of familiarity with technology use. Her/his experiences as an undergraduate, an acquired knowledge of basic techniques and theories, are insufficient for the purpose of making this new environment intelligible. S/he requires further training. Many students and researchers anecdotally recall being told "to forget everything they learned at degree level" as they are initiated into "the world of research". Novice students frequently spend the first year "familiarising themselves" with the experimental apparatus, techniques, procedures, theoretical models, computer simulations, and "the way things are done" within the laboratory. They learn the techniques and tactics. They are also expected to familiarise themselves with "the current literature" and "who's who in the field" as the definition of "the field" and "the state of the art". They also learn what the laboratory group's projects and aims are, who are the group's allies, and who are the group's competitors. In short, the novice student is socialised as a competent group member by being orientated within this specialised technological and social environment. A novice student's prior familiarity with using technologies and her/his undergraduate degree knowledge can only help as a starting point. For the purpose of participating in the specialist character of all scientific research, the idiosyncratic character of particular laboratories' working practices, and the novelty and complexity of the experimental research, degree level knowledge is too general, too basic, and also often obsolete. For example, a third year B.Sc. course in Quantum Mechanics or in Low Temperature Physics would be insufficient for either an understanding of the mathematical models used by an Ultra-Low Temperature Physics research group. The students' education would not provide the level of refinement of skills and technological familiarity required when working upon the experimental apparatus.[2]

Although postgraduate physics students attend general theoretical courses, learning both general

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Geneva. It is also based on experiences I have had with Ph.D. students working in The Ultra-Low Temperature Laboratory at Lancaster University School of Physics and Materials, as well as in other physics laboratories at Bath and Bristol. I have also had discussions with Ph.D. students from other fields of research, including genetics, computational mathematics, chemical engineering, behavioural microbiology, physiological biochemistry, astrophysics, and mechanical engineering from Bath, Bristol, Plymouth, London, Birmingham, and Liverpool universities. In my experience, I have yet to encounter an experimental scientist who is not, to a greater or lesser extent, sympathetic with scientific realism. Most affirm realism about their techno-phenomena, although they do tend towards scepticism about their theories. Physicists, often in reference to the arrogance of nineteenth century classical physicists, tend to acknowledge that their current theories and models are likely to be replaced in the future.

[2] The reader may care to compare Fisher *et. al.* (1989) and McClintock *et. al.* (1992). The former is a published research paper by the ULT physics group in Lancaster and the latter is the course textbook for the Lancaster University third year ULT physics optional course. The former is far more specialised in its inscriptions than the latter. Also, the 1989 paper discusses the insufficiencies of the two-fluid model of superfluidity and proposes an alternative model. The 1992 textbook models superfluidity in terms of the two-fluid model.

mathematical and theoretical techniques, most of the training will be in the context of the specific laboratory work.[3] The novice student needs to rapidly make the highly complicated technological environment intelligible through the mediation of the already established group. S/he learns the methodology. The first stage of this process of orientation requires a great deal of "black-box" abstraction of the group's activities and the experimental apparatus into sequences and series of functions, operations, and procedures. These range from the operations of devices and instruments in specified circumstances to the procedures for recording operations in laboratory notebooks. The novice is taught specific bodily acts and technical operations; this orientates the novice as an experimental practitioner. This form of learning is entirely one of attendance on the part of the student, and instruction (both formal and informal) on the part of the already established group members.[4] It is through this habituation and familiarisation, in terms of "when this gauge reads A then turn that dial to B because this performs function C" instructions, that the technological environment is embodied in practices as a set of techniques. This socialises the student into "how things are done" in terms of operational cause-effect sequences that represent "proper procedures". In this way, the novice learns "how to operate the experimental apparatus" and begins the transition from "novice" student to "competent" student. The novice student also learns, as an equally important part of learning "how things are done", the social dynamics of group relations. The student has to learn behaviour within the social organisation of the laboratory; this orientates her/himself within the "working day" of the laboratory. This involves learning "who is best at what", "how to approach so-and-so" in order to obtain their help, how work tasks are organised, how meetings are organised and resolved, and even how to join in with the group members' "sense of humour". In short, the novice must learn how to negotiate within the group's social organisation. This overtly social side of the laboratory is as equally important as the technical operation of the apparatus for the student's transition from "novice" to "competent". In order to achieve "competence" the student must be orientated in a socio-technological organisation in such a way as to become a negotiator rather than merely instructed. The novice student must survive a process of socialisation through which the student's relationships within the laboratory are both dialectical and didactical. The didactical aspects of the student's relationships are those in which the student learns established practices through following instructions and mimicry. The dialectical aspects are those in which

[3] For example, a first year Ph.D. student at Lancaster's Ultra-low Temperature Physics Laboratory will attend Quantum Physics and Statistical Physics for Low Temperature Physics courses at Manchester University along with first year Ph.D. students from other labs. During such classes the student learns general models and mathematical techniques.

[4] I have used the term "attendance" to denote certain attitudes on the part of the student. This term means more than simply being present. It denotes an attitude of *listening*, *attentiveness*, and *care*. It is used in the same sense as when someone attends to their duties or attends to someone else's needs. This term implies that the student is engaged in more than a passive learning relationship with the other group members. The student is actively orientating him/herself through making his/her working environment and the project(s), in which s/he is a participant, both intelligible and her/his own.

the student negotiates her/his own orientation in the laboratory in relation to other group members and the experimental apparatus through questioning, negotiation, and participation.

However, the praktognosic processes of the embodiment of socio-technical techniques between technological objects and the human body, are necessary but insufficient to make the laboratory environment intelligible and workable. The empirical cause-effect relationships between machine performances and the interventional techniques are exoframed, *from the onset,* with theoretical descriptions of "invisible physical processes". For example, the Lancaster ULT physics student learns that "adjusting the yellow valve marked B changes the pressure of the helium-3 flow" and that "switching on circuit A turns on the magnetic field which initialises an entropic hysteresis loop". S/he learns that when digital display C reads "D" then "the phonon absorption rate has reached a significant level". In the attendance of the student to the "way things are done" s/he both explicitly and tacitly learns connections between techniques and the manipulation of "physical variables". S/he begins to embody the apparatus and it, in turn, becomes an increasingly transparent means of disclosure. The student learns the established interpretation of techniques in terms of "physical processes" as an essential part of making the process of experimentation intelligible. The student is taught how to make the "output", or performance, of the experiment intelligible in terms of interpretive models, mathematical models, theoretical conceptualisations, and visual representations of invisible "physical processes" that are claimed to be occurring within the experimental closed system. The student learns "how to see" and the apparatus becomes a means of disclosure. This part of the learning process occurs simultaneously with all the other parts. The student gradually learns how to perform the socio-technical procedures and how to make sense of this performance in terms of experimenting upon "a physical process". This learning process occurs throughout the whole process of education as a research student. This tacit connectivity between socio-technical procedures and the remote manipulation of theoretical entities is an interpretive, technical, and cognitive orientation within the process of making the laboratory intelligible. Embodying this tacit connectivity in practice allows the novice student to participate in "doing physics". It is this embodiment which makes the abstract level of theoretical physics manifest in, and linked to, the manipulative practices of the operation of the apparatus. The "physical properties" then can be "actualised" by pressing switches, or turning knobs, which tacitly relate techniques to "adjusting energies", or "quantum states", or "temperature", or "magnetic polarisation", etc. At all stages of the learning process the student is taught by the other group members how to make sense of her/his experiences for her/himself in terms of intelligible practices. It is by orientation of her/himself to the social processes involved in interpreting the performances of the apparatus that the student learns how to conduct scientific negotiation, and reasoning, and becomes a scientific negotiator and reasoner. The extent to which the student will be perceived by the already established group members to have become "competent" will be dependent upon the student's success in orientating her/himself within the context of the group's practices in such a way as to cohere with the group. It is by doing this that the student will be perceived by the other group members as having acquired the skills necessary to do the work. The student will become competent by embodying the methodology of physics and mathematical projection; by learning how to embody that methodology for her/himself.

A research group is not comprised of homogeneous individuals. A research group does not constitute a simple social agency. Research scientists, like people from all walks of life, are idiosyncratic and have divergent interests, and constitute social agents in their own right, which may, or may not, cohere with the group in which they are situated. The student often receives quite a diversity of opinion from the group members about "how to do physics", "how to solve this particular problem", or even if "there is a problem here". Of course, the diversity of opinion will remain within the template of the methodology that they all share. Hence, they are performing the same experiment and their experiences are commensurable. From within the boundaries and constraints of these opinions the student has considerable space for negotiation and selection. The student has to work out *for her/himself* which member of the group provides "the best advice" in any given situation because the group may not provide a unified answer to this question. This will depend on perceptions of competence, credibility, and the potential outcome of interpersonal interactions. The student may find that, although the other group members consider "Dr. A" to be the most proficient at a particular technique, or explanatory tactic, s/he is able to communicate with, and consequently understand, "Dr. B" better. The group members may also be divided on the question of who is most competent and the student has to learn how to navigate these divisions. The course of navigation will vary from circumstance to circumstance and depends on the dynamic interchange between group members and the student during the periods of negotiation. Often the student will encounter diverse opinions on interpretations, visualisations, or appropriate techniques, in either group discussion, or interpersonal discussion between the student and another individual, and the student is very much left to make judgements *for her/himself* as to the best way to proceed.[5] The student is very much a negotiator in her/his own learning process. The group may well share a commitment to make the experiments they perform work well, and to publish excellent results, but they may not necessarily agree about what constitutes "working well" and "excellent results". In the process of experimental work there is a dynamic social process of social agents engaged in the negotiation of "how to proceed". This dynamic social process is directed to transform a collection of diverse social agents into a unified convergent social agency. The establishment of convergent and stable group practices is the establishment of coherent social ageny within a wider social context. This give the laboratory "one voice" in interaction with other laboratories, conferences, funding bodies, etc. The student also has to learn that many of the choices that the group makes are not always made on "scientific" criteria. Economic and political factors are involved in the group's choices of projects in order to gain prestige for the group, attract funding, attract media attention, undermine a rival group, etc.[6] I agree with Karin Knorr-Cetina's argument that laboratory work exists in

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[5] Often postgraduate students find themselves being told to do something a certain way by one established member of the group only to find, that later, another established member of the group tells the student that s/he is doing it all wrong and should do it another way.

[6] For example, the ULT physics group chose to channel many of their efforts into building a larger dilution

trans-scientific fields.[7] Choices are *trans-scientific* selections because they are made in contexts of resource relationships, interests, and social connections that transcend the laboratory. As Woolgar & Latour have argued, scientists make choices on the basis of credibility, perceptions of risk, and career investment criteria.[8] The point that these authors are making is that scientists' choices are not made solely in terms of internal logic, or scientific rationality, but are based on opportunism within a wider social context. The student learns, as a social agent, that being a scientific negotiator involves being a negotiator in a wider context than the laboratory.

Experimental physics is a highly complicated and "messy" affair. The novice student has to learn, from the other members of the group, how to make skilled judgements about how to proceed with the work. Experimental apparatus do not always work in accordance with the expectations of scientists. In fact, many experimentalists often joke that experiments rarely work in accordance with expectations. The novice student learns the intentions and expectations of the group in the context of frequent instability and complexity. S/he learns what constitutes "working well" as well as "what to do", "how to do it", and "when to do it", from the other group members' experiences of dealing with the instabilities and complexities in their work as they attempt to stabilise successful working practices. In this way s/he acquires the received wisdom of "how to perform experimental physics" and "what the results should look like" if the experiment is "working properly". The embodiment of "the best way to proceed" to "achieve realistic goals" is passed on to the student through this orientation of the student's expectations and practices in line with the group's established and stable expectations and practices. The student also learns, in parallel to "working well", what constitutes a "breakdown". S/he learns "likely causes" of "breakdown", the "whys", and "the best way to fix it", as part of the process of familiarisation with the groups tacitly embodied history of trial and error experiences, modifications, interpretations, and transdictions. The "best way to fix this" is often a particular solution to a "failure" which is pragmatically taken to be *the solution* provided it remains stable. For example, the student may well learn that if a particular characteristic signal appears on a spectrograph and is considered by the already established group members to be "noise", and consequently "undesirable",

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refrigerator in order to achieve lower temperatures and break their own low temperature record. Two members of the group expressed reservations about this because they claimed that this effort was about technological innovation, purely to gain prestige, and that their efforts would be better spent doing physics at the temperatures that they had already reached. Also, when a member of a visiting group from Nottingham came to present that group's work on using polarised He-3 as part of a new lung imaging technique, a few of the Lancaster group tried to convince the visitor that Xenon could be an equally viable gas for the task. This was not based on any commitment to find the best gas for lung imaging, nor any knowledge of the appropriateness of xenon for this new technique. It was an expression of the Lancaster members' concern that if medical research used He-3 then the price of the gas would be raised and reduce the group's available resources.

[7] Knorr-Cetina (1981).

[8] Latour & Woolgar (1979).

then it should be "fixed", or "removed", by "changing a connecting cable", "adjusting the signal amplification", or whatever. Much of experimental physics involves the acquisition of a collection of experiences of "jury-rigging", tinkering with the technological configuration in order to maintain a stable output in line with expectations.[9] It is only when such "jury-rigging" attempts persistently "fail" and that the output persistently "fails" to meet expectations that the experimental practitioners will look "deeper". This "deeper" look involves the determination of stark closure: either there is a serious problem with the construction of the experimental apparatus, the performance of particular procedures, or there is "new physics". Either way "something is misunderstood". This closure occurs when stability is achieved. This closure is performed by running through a list of possible transdictions and then either removing possible sources (until it vanishes) or exploring it through subsequent innovation (making it instrumental in the performance of its own disclosure). If the expected output can be achieved and stabilised by re-building part, or all, of the experimental apparatus then the problem is determined to be one of apparatus design or construction: "The experimental apparatus was flawed." If the expected output can be achieved and stabilised by using a different technique, or simply by someone else performing it, then the problem is determined to be simply a matter of practice: "The experiment was performed badly." If the expected results cannot be achieved through changing the apparatus design or operation then (typically *only then*) "new physics" will be suspected. Only if the anomaly remains stable *and* an impediment to the research project will it be considered worthy of further investigation. Otherwise it will be avoided and the work will continue as before.[10] However, anomalies are considered when an alternative hypothesis is abductively[11] presented to account for the anomaly and suggest a new direction for experimental research. Without this "explanation" the experimental result rarely is considered "publishable" and is often considered to be a

[9] It is this tinkering which Pickering (1995) terms "a dialectic of accommodations and resistances" and the collection of experiences constitutes "the emergent contours" of material and human agency. I shall discuss Pickering's thesis in the next chapter.

[10] During one of my visits to the ULT laboratory at Lancaster the group observed an anomalous "cooling spike" on the readout of one of their dilution refrigerators. This did not make any sense to the group members in terms of their theoretical expectations. It was immediately rejected, transdicted, as not a real cooling effect and treated as artificial. The last change that the group had made to that particular component of the experimental cell was to coat its walls with a plastic called Capton. The group removed the substance, the spike did not reappear, and it was paid no more attention. To date the group has not used Capton again in the construction of their cell walls. No work has been done on "the Capton effect" transdiction.

[11] Peirce defined abduction to mean the general process of inference whereby a conjecture is made of the form (1) Observe an anomaly, (2) Abduct a hypothesis from which the anomaly deductively follows, (3) test other derivative predictions from the hypothesis by experiment. This is essentially the method of implementing transdictions. Gooding (1996) discusses the potential role of abduction in contemporary science.

"dead end". The extent to which Popper's "falsification principle" is a principle in scientific work is that, *in principle*, any scientific theory or hypothesis should be falsifiable, but working physicists rarely spend any time falsifying hypotheses or theories.[12] Most scientific endeavours are attempts to make things work and a theory or hypothesis will only be rejected if it consistently fails to work *and* there is an alternative which seems workable. If a practice, technique, interpretation, theory, or tactic, is working well within the coherent social agency of the group, then it will be *pragmatically* continued to be used whilst the group members deal with more interesting or problematical matters. It is this pragmatic acceptance of practices within coherent group agency that establishes stable technological objects. The stable technological object is made pragmatically meaningful through training and demonstration in such a way as to "explain" the meaning of the practices by showing its intended effect in the context of the work. The purposes of practices are given a pragmatic basis of meaning in terms of their usefulness, which the student learns through mimetic attendance towards the uses, the intentions, and the expectations, implicit in the group's practices.

Through the above processes the student, in transition from "novice" to "competent" student, is orientated within the developing stable labour processes of the group in such a way as to become a negotiator within the group. A stable labour process constitutes simultaneously both a stable social order and a stable technological order. It is a socio-technical organisation of technological objects and bodily motility. When it is directed towards efficiency it is characteristic of Ellul's *technique*. In the context of production, "order" is determined pragmatically in terms of "stability" and "reproduction". Any change of the group labour processes will occur in response to "disorder" and "instability" and will become established if it is deemed to promote "order" and "stability". This moment of establishment occurs as the group moves from being an incoherent collection of divergent and heterogeneous socio-technical agents to becoming an integrated, convergent, and coherent socio-technical agent. In this way the "way of doing physics" develops in accordance with ongoing socio-technological process of the stabilisation of labour processes in response to periods of instability and disorder. Stability and order form an established convention of "the way of doing things" into which future novice students will be socialised and orientated. This established convention is open to re-evaluation as the group dynamic moves between periods of incoherence and coherence regarding "the best way to do this" as they encounter disorder and instability. Whilst the group is in a period of coherence a socio-technological convention is stabilised and whilst the group is in a period of incoherence conventions are open for negotiation. These periods of incoherence

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[12] Due to the problem of ancillary hypotheses being required as well as the primary hypothesis, the hypothesis under investigation cannot be straightforwardly falsified. We cannot know whether one of the assumptions used to deduce a particular observable from a general law, one of the assumptions used to construct the test, or if the hypothesis itself was false. This requires further testing and also further assumptions. Although, in principle, Popper's falsification method seems straightforward, in practice, it is unworkable. Even Popper was aware of this. Working physicists, if they are aware of it, tend to pay Popper's falsification method "lip service" and then get on with their work.

occur as the group encounters new problems and the periods of coherence occur as the group completes a period of negotiation as to what the solution of these new problems are. These new problems arise because in innovative and complicated work, such as experimental physics, the socio-technological order is *underdetermined* and heterogeneous. It is fragile and fragmentary. It is experimental.

What does the term "experimental" mean? In experimental work, technologies are used for purposes other than the use for which they were developed. The tools, components, and instruments, are often used for tasks other than those for which they were originally designed, and, consequently, their use, in terms of what can be done with them, is not fully determined from the onset. It remains to be determined through use from within a template of possibilities. It is underdetermined. Underdeterminacy is distinct from indeterminacy. The former means that a particular tool has not been completely determined in its usage *yet* whereas the latter means that its usage is ambiguous. Furthermore, the interaction between changes in the technological configurations of the apparatus and its responses to those changes are also underdetermined (otherwise there would be nothing to experiment upon). It is the underdetermined character of the socio-technological order that opens a space for choice in the selections and directions which are available to physicists. It is this space for choice that allows considerable free-play in scientific work in which incoherence between social agents is possible due to the availability of divergent selections and directions. This space allows an experiment to begin. The determination of the labour processes of the group and the technological configuration of the laboratory and experiment removes this free-space; the establishment of coherence fills that space. It is impossible to determine the content of a final socio-technological order from the onset. This has to be developed *experimentally* through periods of disorder and ordering. In other words, the development of a stable social and technological ordering is incomplete, experimental, and no one is able to determine, *in advance*, exactly what form it will finally take when it is complete.[13] The working physicists may well have expectations, as to what the final form might be, but these expectations are re-evaluated and transformed during the process of ordering the social and technological dimensions of the work. Provided that they remain within the template of the methodology of their institutionalised field of research, they have considerable free-play in the construction of their plan of action. Furthermore, the technological objects used in experimental work were constructed in heterogeneous contexts. Each object is a centre of transformative power when in a context in which it has been stabilised as a technological object. An innovative process is one of converging heterogeneous objects and integrating these diverse centres of transformative powers into a single convergent, stable, and coherent centre of transformative power in the novel context. This creates a novel prototype available as a technological object for future experiments. This is how novel machine-families are created: as hybrids of others. It is also how physics progresses and specialisation occurs.

Experimentation is an inherently innovative development of both social and technological orders in terms of the achievement of stable labour processes. It is a highly developed form of social activity that, for all but the most trivial experiments, requires co-operation, resources, and complex machinery. The co-

[13] On this point I agree with Pickering's argument. See next chapter for further discussion.

operation involved has two primary spheres of operation. It has an "external" sphere in which the co-operation of non-physicists is required to provide the resources and facilities for the construction of a space in which an experiment can occur. It also has an "internal" sphere in which the co-operation between physicists is required for the successful design, construction, operation, inscription, and interpretation of the experiment. Thus the rhetorical task of setting-up an experiment is two-fold: the experiment must be presented as having an external value (i.e. value for economic, military, or political purposes) *and* as having an internal value for the ongoing activities of research (i.e. value for scientific purposes). Each experiment must be set-up as instrumental for the satisfaction of purposes, which are built into the set-up (unless the physicists involved are being deceptive). It is due to this two-fold task that experimental physics is both transcientific and teleological (internally directed towards the achievement of its goals). Every experiment, from its set-up to its completion, is a two-fold technological object within two spheres of purposes; within the "internal" world of ongoing scientific research and the "external" world of economical, political, and military ambitions. Each physicist, when positing the value of the experiment, is positing purposes and goals to other people that the experiment has, at least in part, the potential to satisfy. Physicists, in order to persuade themselves and others of the experiment's potential, must do so in relation to the conventional background of expectations, estimations, and acceptance of what is possible, probable, or even necessary. Thus every experiment is set-up in relation to paradigmatic technological backgrounds, against which it is foregrounded as an exemplar, within the "internal" trajectory of ongoing research and the "external" trajectories of the wider world's desires for further technological innovation and power. From within these trajectories particular exemplary experiments are publicly presented as necessary (or crucial) for the further progression of those trajectories. In this sense, experiments are suggested by paradigmatic backgrounds of ongoing scientific research and technological innovation. The physicists are *challenged* by these suggestions to set-up and perform the experiments that publicly emerge as necessary, crucial, probable, or even merely possible. From within complex experiments a further series of related experiments emerge as necessary, crucial, probable, and possible, and the participants will be challenged to construct and perform them next. It is in this sense that an historical understanding of the ground-plan of the set-up and trajectory of experiments is *necessary* for us to have an understanding of contemporary experimental physics. The trajectories of ongoing research and technological innovation are *Ge-stell* for which the background efforts are standing-reserve for the destining of experimental physics. Furthermore, due to the need for their co-operation, the physicist is also positing purposes and goals for other people. The highly complex machines and infrastructure required by modern physics (i.e. ULT physics at Lancaster or HE physics at CERN) require division of labour in order to function successfully as research. The individual participants are defined in terms of their roles (i.e. physicists, engineers, technicians, mathematicians, students, theoreticians, and computer scientists) as they are ordered according to their techniques, under the challenging and destining of *Ge-stell*. Each one of these techniques is defined according to the postulation of a purpose within the complex of purposes ordered towards the purpose of the whole. The work of individual participants is two-fold: each participant attempts to elicit performances from their part of the machine interface *and* from other human participants. The object of their labour is not just the performances of the machine but is also the performances of the whole, interconnected complex of participants upon which the performativity of the machine depends. Thus the means to achieve machine performativity are orientated towards both the machine and the group of human participants. This is enframing. The means are not simply those required to achieve performances from machines but also to achieve performances from other people. The purposes and goals postulated in such complex experiments are socio-technical and are not simply rational orientations towards theoretical derivations. Machine performativity emerges from the *Ge-stell* of socio-technical labour upon materials, inscriptions, and other people, and is not a simple test of theory. The teleological positings of labour[14] are the challenges of *Ge-stell* and where "theory testing" plays a role in an experiment it is as a challenge within the complex of interconnected challenges set-up by *Ge-stell.* If complex experiments can be said to be a test then it is a test of the socio-technical agency that is gathered and challenged to construct and perform the experiment. It does not immediately follow from the success of agency that any theory utilised in the experiment was correct (or even approximately correct). All that immediately follows is that yet another challenge has been undertaken and completed.

The stabilisation of socio-technical practice result in the concrete realisation of a techno-phenomenon that is produced through the contingent activities and choices made during the efforts to stabilise those practices. It does not follow that techno-phenomena realised in this way were waiting to be discovered, or were actualised in accordance with natural law. What is discovered is how to stabilise those practices. In my view, J.J. Thompson did not discover the electron as something waiting to be discovered but, rather, discovered how to make the electron a stable part of the ongoing extension of the electromagnetic machine-family. Given that the electron only exercises its powers within the contexts of this machine-family, then it is irrelevant whether it is a "real and out there" fundamental corpuscle of matter because *what an electron is* is enframed by what it does within the ongoing researches of experimental physics. Its reality is inextricably bound up with the character of these researches and it is *that electron* which is the object of scientific discourse. The electron is a technological object. Thus its reality should not be divorced from the socio-technical processes in which it is stabilised and utilised as a technological object. The technique of spraying electrons is available as standing-reserve for challenges by *Ge-stell* and its disclosure is identical with its responses to those challenges. The electron of scientific discourse does not have any scientific reality outside of the ongoing *Ge-stell* of research because if it were to have ontological independence from *Ge-stell* then these facets of its being will not be utilisable and, consequently, be inaccessible to scientific research. It would be outside the ground-plan. The labour processes involved in the stabilisation of technological objects; this requires bringing together and ordering diverse and heterogeneous technological objects across the borders between machine-families. These objects can be skills, practices, machines, exoframes, models, metaphors, representations, mechanisms, tools, materials, techniques, or inscriptions. The innovative processes of stabilisation involve the

[14] see Lukacs (1978)

convergence of divergent and incoherent centres of transformative power into a single convergent and coherent centre of transformative power. This is a process of producing a stable technological object from many technological objects. Thus all technological objects are complex manifestations of a historical labour process. This manifestation emerges from a struggle with contradictions, incoherence, divergence, heterogeneity, and plurality that are implicit in, and emergent from, the extension and synthesis of distinct machine-kinds into a novel machine-kind. Once this is stabilised it is presented as a defined and self-contained technological object utilisable for the exploration of a "deeper and more unified strata of reality". Thus the extension and synthesis of a compass (a magnetic machine) and a chemical battery and wire combine (an electrical machine) into Oersted's apparatus (an electromagnetic machine) could, once stabilised, be presented and utilised as a technological object for the disclosure of the deeper and more unified strata of forces. Mechanical realist metaphysics allows the extension and synthesis of machine-kinds to be presented as the disclosure of "ontological depth". The frontiers of new experimental physics, at any time, are the new challenges of *Ge-stell* and the already stabilised technological objects of prior efforts achieve their reality to the extent that they are available as standing-reserve. In this way, the destining of *Ge-stell*, as the destining of physics, promises novel technological complexes of objects that will challenge the labour processes of physicists to disclose deeper ontological strata. The frontier of physics attains an ontological "superiority" over the past efforts that its destining is entirely dependent upon. This order of rank is entirely one of the "superiority" of challenges over standing-reserve. It is an expression of the desire for novelty. The new strata of machine-kinds, the novel machine-family, is the "cutting-edge" or "state of the art" of novel physics that is manifest as a research programme through its subsequent innovation into further differentiated machines. The ontology of experimental High Energy Physics is circumscribed by the permutations of particle detectors and accelerators. These permutations are innovated by the extension and synthesis of the same component machine-kinds. It is this process of differentiation from a shared set of technological objects that unifies High Energy Physics as a research programme and provides its technological objects with transfactuality. It is only due to the fact that the LEP accelerator at CERN and the SLAC in the United States are constructed from the same component machine-kinds that the "particles" that they both produce are describable using the same models and theories. This fact is a consequence of the fact that the same models and theories were built into both machines through the processes of stabilising the convergence of the same machine-kinds during the design and construction of those machines. It does not follow from the fact that these machines are different that they are independent. There are merely different ensembles, different configurations, of the same component technological objects and, as such, are members of the same machine-family. The extent that these machines are taken to be independent, or autonomous, is a consequence of the extent that their shared component machine-kinds have become transparent as standing-reserve.

The modelling of these machines, in relation to the labour processes of the research programmes that circumscribe them, is a process of positing causal relations and mechanisms that are relevant to the particular goals of that research programme. The transference of these models between members of the same machine-family, as a process of cross-checking and modifying both the models and the performativity of the machines, transforms the posited causal relations into a more codified and abstract form and leads to their generalisation. The experiences of the research workers on one particular machine can be related to the experiences of the research workers on another particular machine, through these generalised models, providing that the machines are members of the same machine-family. The physicists working on DESY in Hamburg, the DELPHI detector at CERN, and the SLAC machine in the United States, can relate their experiences through the abstract and codified Standard Model of Elementary Particle Interactions. This occurs despite the fact that this general model needs to be extensively expanded and modified to be of any use in exoframing their particular projects. By relating their experiences in terms of a shared general model the physicists are able to generalise and unify their experiences as experiences of the same kind of events, and, as a consequence, transcend the particularity of the specific machine performances. It is only in relation to a shared general model that these physicists are able to translate their particular experiences of the particular performances of particular machines into general observations of the same processes. This endows those events with autonomy and transfactuality. This transfactuality should not be of any surprise given that it was built into the machines from the onset and has been continually maintained by the experimenters in their interpretations of their experiences. The use of general models also allows the physicist to de-personalise their experiences and present them as the experiences that anyone would have (providing that they were familiar with the general model). It is this de-personalisation that is presented as objectivity and facilitates the removal of the particular labour processes that were necessary for the physicist to have those experiences, from the final accounts. This is an example of reification (Lukacs, 1967, pp.83-109). The transfactuality of those experiences are merely a consequence of the exchange of experiences in terms of a shared general model that is both built into the design of the particular machines and is used to interpret their performances. Without a general model those experiences would be incommensurable because they would lack any common frame of reference, and, therefore, the use of a general model is a precondition for any division of labour within ongoing experimental research programmes. The use of a general model is also a precondition for the subdivision of any research programme into particular experiments and further specialisation. The experiments and theories of modern physics, presented as autonomous and transfactual in terms of a general model, can only be divorced from the challenges of *Ge-stell* and the teleological positings of the labour process by presuming the validity of the precepts of mechanical realist metaphysics. This is an expression of the public conflation of *techne* and *episteme* that has been central to experimental physics since its onset in the work of Galileo. The general causal accounts of the stable products of the socio-technical processes of labour can be presented as universal knowledge of the eternal and fixed efficient causes of Nature in terms of the general mathematical laws that describe them. It is at that point that both human agency and machine performativity have been written out of the account completely. This conceals the teleological positing that is inherent in the destining of experimental physics because, by presenting the directions and products of physics as the disclosure of natural processes, it has hidden both the "internal" and "external" spheres of purposes and challenges for which the experiments were set-up to satisfy. This concealment hides the beings for which the disclosures of physics are truths and powers, and, as a consequence, not only hides the choices that have been made regarding the human inquiry into Nature but also hides the fundamental relation to Being that provides the precondition for those choices. It is as a result of this concealment that *Ge-stell* became the natural mode for being-in-the-world, and, simultaneously, became concealed from presence as *Ge-stell*.

Models and Intelligibility:

As Nick Maxwell pointed out (1984), we must not forget what sort of being scientific theories and models are intelligible for. Once we address intelligibility as a central criterion for theory and model choice then we can not remove the living bodily being, namely scientifically persuaded human beings, for whom those theories and models are intelligible, without removing their intelligibility. Furthermore, as the choice of theory or model is bound up with the choice of research programme, then we can not detach the question of which theories and models are to be explored from the teleological positings in the "external" world of commercial, political, and military ambitions, that the direction of research has promised to satisfy in exchange for resources, equipment, and space. Modern experimental physics is situated between two dimensions of productive activity: the "internal" dimension of the production of intelligible explanations of machine performativity in terms of natural laws and mechanisms, and the "external" dimension of the production of innovative transformative powers and machine prototypes. In contemporary science studies there has been a great deal of emphasis of the roles of models in the construction and establishment of scientific knowledge. Leatherdale (1974) provided an extensive summary of available literature on the subject of models in science in the mid-70s, and Rom Harré (1961) considered explanatory models to be central to a realist interpretation of physics in the early 60s. The volumes have swollen considerably since. Models have been considered to be central in scientific reasoning by an extensive collection of analysts of science from diverse academic disciplines. Many scientists have also emphasised the central role of models in constructing and articulating scientific theories and explanations. The processes of scientific description and reasoning are essentially that of modelling and exoframing.

A model of any real process is inherently a simplification, abstraction, and an approximation of that process. In experimental physics, the labour processes of making a model involve abstracting the mechanisms and functions of the apparatus in order to make manipulation of the model as simple as is pragmatically acceptable whilst simultaneously making selections as to which features of the apparatus' configuration are essential. The purpose of a model is two-fold: it is made to both represent reality and to simplify it. Physicists, when constructing models, have to make a choice between making the model simpler (easier to work with) or making it more complex (realistic). As Gleick pointed out (1987, pp.278-9), the purpose of a model is to abstract, picture, and generalise a real process, or the world, and only the most naive empiricist would claim that a perfect model is one which perfectly represents reality. If a model were to mimic reality in every detail then we would not have any need of the model at all. Models relate "inner" (or "hidden") structures, mechanisms, functions, or properties, to objects, phenomena, or systems, in order to explain the various properties that they have. Models are taken to be "approximations" or "simplifications" of "the actual phenomenon". Models allow the processes of experimentation to continue through selecting "the essential features" of phenomena and the interactive relationship between experimental procedures and "physical variables". As such, models have both instrumental value and make ontological claims; a model both is a tentative, and re-evaluative, pragmatic tool, and a "description" evaluated according to its truth. A model is an essential link between a mathematical theory and experiment without which the mathematics is not scientific at all because it lacks an exoframe by which it is connected to the machine performances of the interconnected apparatus and calibrated instrumentation. Models have an explanatory function and are essential for the heuristic of scientific discovery to occur at all. Models allow mathematical expressions to be used as functives within exoframes. These relate the calibrated instruments and machine performativity of apparatus with the "physical processes" that are being experimented upon by providing a visual, descriptive, manipulable, and intelligible representation of both mathematical formulation and the varying instrumental displays of physical apparatus. Models are transferable across contexts in which a common abstract feature between those contexts allows the implementation of the same abstract model. For example, Laplace's equations serve as a mathematical model for quantifiable change in diverse fields such as gravitation, electrostatics, electricity, elasticity, and liquid flow. Models combine abstractions and simplifications of dynamic and functional aspects of phenomena and how they inter-relate. They are used to design and construct instruments, experiments, computer simulations, calibrate measuring devices, and interpret experiences. Models have numerous rôles in scientific work. A model can have an *explanative* role if it provides a description in terms of a narrative and/or imagery. Through verbalisation and/or visualisation the "novel" can be related to the familiar. In this way a model can be used to "make sense" out of a phenomenon by relating it to things that are already "well understood". An example of using a model in this way would be the wave theory of light, which can be demonstrated using ripples in water to explain phenomena such as refraction and diffraction. A model can have a *semantic* role if it is used to relate technical and "common" language in such a way as to broaden the context of any scientific work from specific contexts to more public ones. Such a model trades off precision for generality at the cost of introducing ambiguity. It is often necessary to do this in order to make a technical model intelligible in ordinary language. An example would be the re-description of matrix operations in Heisenberg's matrix quantum mechanics in terms of observational events in order to be able to make sense out of the mathematics in a physical context. Another example would be the relation of the technical definition of "wave" in mathematical theory to the more broader, and ambiguous, meanings in "everyday" public language. A model can have an *ontological* role if it is used as the phenomenon, which it is supposed to represent. Such a model is said to possess verisimilitude; it approximates the truth, and maintains its "ontological realism" through the commitment of its adherents and allies. If one believed that light was really comprised of waves then the wave theory of light would be superimposed upon the phenomenon of light. The model is a metaphor and replaces the phenomenon under investigation. The physicists skip over the phenomenon and interact with the model as if it were the phenomenon. A model can have a *heuristic* role if it acts as an aid to insight, innovation, and/or discovery. Such a model is not necessarily considered to be ontologically realistic but rather inspirational. The wave theory of matter would be an example of this. Although very few people publicly admitted to believing that matter was propagated in waves in published discussions at the beginning of the twentieth century, it was readily apparent that such a model opened up interesting new physics in terms of new experiments and theories. A model can have a *logical* role if it aids logical, mathematical, and computational analysis of a problem. The wave theory of probabilities applied to "sub-atomic" behaviour is an example of this, as it provides both a framework in which calculations can be made and also a logical structure through which "thought-experiments" can be constructed. A model can have a *predictive* role if it is used not only to calculate numerical values in relation to any variation of factors but also if it can be used to derive new hypotheses, theoretical conceptions, and possible observations. An example of this would be the derivation of astronomical topological events from General Relativity. The General Theory of Relativity offered such a large number of exciting new predictions and it was adopted as an interesting model long before any possible techniques for observing these predictions were even imaginable. Even today, although this theory is well established within modern physics, there are no incontestable "observations" of entities such as black holes, worm holes, white holes, etc. A model can have an *instrumental role* if it is used because it works within the context of the project without ontological commitment. Many physicists use quantum mechanics in this way. It facilitates calculations and predictions but the physicists do not necessarily commit themselves to its reality. Such models are used instrumentally as a technique. These roles are interconnected, any model may be performing two or more roles simultaneously in practice, and often the rôle that a model is performing is ambiguous. Models are also used both *techneically* to explain the performance of the apparatus and also *epistemeically* to explain the behaviour of phenomena. In an ongoing physics experiment, the apparatus is itself constructed according models of the performativity, how those components will relate to one another, and how they will interact with the phenomenon under investigation. The apparatus embodies many such models which can be used both epistemeically and techneically. These models were built into the apparatus in its set-up.

By using models to simplicity, or clarify, complicated phenomena, physicists are able to use a model to provide intelligibility, cognition, and articulation. This allows for the selection and summary of experience in terms of essential features. Models are also modifiable and manipulable, and have capacities to accommodate development and change. In physics this is an essential feature of experimental models. Much of the work of physicists involves modifying the models used to accommodate discrepancies and problems that arise in their use, as the model needs to accommodate changes in the configuration of the apparatus. It is also an essential part of a model that it is exoframed to allow for the quantification of properties (an essential factor for measurement) and represents the phenomenon as a set of mathematical relations between functions, variables and constants. This involves "slicing" the phenomenon into mathematical functions, which relate independent variables. This is necessary for mathematics to participate in exoframing. It is also essential to be able to model the apparatus in terms of functional sequences and relations, which are connectable to operations and procedures. Epistemeic and techneic uses of models are inter-connected in order to model the complete physical experiment. This connects the manipulative procedures of experimentation with "physical variables" through exoframing the phenomenon as a set of functives. Both the configurations of the exoframed apparatus and the exoframed model are modified together as the techno-phenomena are disclosed. The technophenomenon is, of course, eventually predictable using the latest model-exoframe. Then the physicists publish.

How are models constructed? A model, as a simplification and generalisation of a phenomenon or process, is a robust and manipulable likeness of the phenomenon or process in question. In virtue of being a likeness, models are analogies (often on many different levels of likeness). An analogy allows description of novel phenomena in familiar terms and suggests further inquiry in exploring the fullness of the analogy. By using analogies scientists are able to explore a whole complex of analysis of implication and association which facilitates a further exploration of relations suggested by the analogy. With continued work this process of analogical reasoning and visualisation leads to the construction of a model. This process is one that begins with the inspiration of a tentative analogy, a simple likeness or simile, and finishes with the construction of a robust analogy in the form of a model. For example, the kinetic theory of gases was based upon an analogy with the mechanical properties of common material objects.[15] Bacon regarded the use of analogy as essential to scientific thinking because the investigation and observation of resemblance and analogies provides us with a sense of the unity of Nature and a foundation for scientific inquiry.[16] The view that analogy is an indispensable instrument for scientific exploration, was expressed by Oppenheimer (1956, p.130). Hooke, Kepler, Mach, Maxwell, and Poincaré, also who recognised the important role of analogy in scientific discovery and work. Analogy is a fundamental technique for mathematical abstraction and aids intelligibility. It allows mathematics to participate in exoframing and the phenomenon to be compared to something familiar. It also allows phenomena to be drawn in terms of visual representations. Gooding (1990, ch.4) described "curves of force" – one of the central visualisations in electromagnetic theory – *as an analogy* which featured prominently in the process of constructing stable and communicable experiences within the context of Faraday's, and others', experimental work. It is via using analogies such as "curves of force" that Faraday *et. al.* were able to visualise the phenomena under investigation and construct mechanical models. Gooding shows how Faraday continually oscillated between the development of experimental techniques and the construction of his models in order to inform each other. As such his experimental work was actively constructive in the development of stable theoretical models and vice versa. There are many other examples of analogical reasoning and modelling in the history of science. Galileo used the Jovian satellite system as an analogical support for Copernicus' heliocentric solar system. Kepler used an analogy between musical harmonics and planetary orbital geometry. Newton used a terrestrial projectile as an analogy for the Moon. Bohr used the heliocentric solar system as an analogy for the hydrogen atom. The use of analogies as both a model and support for a hypothesis, or theory, can be

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[15] A point made by Harré (1961) p.22

[16] *Novum Organum*. p.47, pp. 144-7, pp.180-1

found throughout modern physics. The free electron theory of metals, the kinetic theory of ideal gases, the Ising theory of ferromagnetism, the Standard Model of Elementary Particle Interactions, the Big Bang theory, etc., are all examples of models based on approximations and likeness, and hence analogies.

Analogy also plays a synthetic role in bringing together heterogeneous domains of experience and gives science interdisciplinary means to cross over boundaries between distinct specialisations. Throughout the history of physics new models are often emergent when two previously distinct disciplines, or specialisms, are brought together. For example, cosmologists trying to understand "dark matter" have sought a mechanism by which it can be detected. In ULT physics "superfluidity" (itself an analogy) can be taken to be an analogy for "a vacuum" in which changes in "the AB-boundary position", between "the A-phase of superfluid He-3" and "the B-phase of superfluid He-3", are taken to be analogous to "the symmetry breaking" that "occurs because of certain cosmological strings of dark matter" that are "predicted" by "the Inflationary Phase of the Big Bang" model (itself an analogy). It is because of analogical reasoning like this that a ULT physics "dilution refrigerator" can be used as a possible "dark matter detector" and the two previously distinct specialisations of ULT physics and Theoretical Cosmology can be brought together.[17] Also, by bringing together previously heterogeneous experiences the physicist can transfer her/his experiences from one experimental project to another. In this way both experience and practices can be transferred between projects. It is through analogy that experimenters can find starting points in new projects and build novel experiments. New experiments can be analogously modelled on old experiments. Morpurgo's experiment to find free-quarks using an analogous construction to Millikan's oil-drop experiment is a good example of the way that analogous reasoning provides physicists with a guide for how to begin an experiment. Analogical reasoning allows one machine to be used as an analogy of a potential innovation in another context. It allows techniques, *tactics*, labour processes, skills, expertise, models, exoframes, technographics, and machines, to be moved through the intersections between connected machine-families by noting the analogies between the machine performances in different productive and theoretical contexts.

There are two common uses of analogy in scientific reasoning. One signifies a likeness of form and the other signifies a likeness of function. The analogy between the solar system and the atom is of the former usage whereas the analogy between the heart and a pump is of the latter usage. Many models in physics, such as Schrödinger's probability wave quantum mechanics, offer both function and form modelling. This combination of visual modelling and behaviour modelling, achieved through the connection of visual representations and mathematical functions, allows a model to act both techneically and epistemeically by simultaneously modelling how something works and what something is. This is evident in the experimental work of the ULT physics group at Lancaster in whom the functioning of the apparatus is construed in terms of the mechanisms of theoretical entities such as "entropy", "AB boundary phase changes", "thermal coupling constants", "specific heat capacities", etc. The technological

[17] See Bradley *et al.* (1995) and Bäuerler *et al.* (1996a,b, 1998) for the Lancaster ULT physics published work on these models.

configuration of the apparatus is modelled in terms of theoretical constants and variables, which are reciprocally reconfigured in the adjustments made the mechanistic configurations of the apparatus. For example, "the heat switches" that separate the "upper" and "lower" sections of a dilution refrigerator are chosen because of their property of "superconductivity at specific temperatures".[18] The apparatus has had working models embodied into it through the choices of components made by the physicists at every stage of its construction and operation. This is even more evident in the work done by experimenters at DELPHI, CERN, where the 10m x 10m barrel of electronics, wires, magnets, detectors, tubes, and iron, is intricately made meaningful in terms of models of its responsiveness to different models of particle physics (itself an analogy). At every stage of its design and construction the choices made by the physicists were taken on the basis of their models of elementary particle interactions and material responsiveness. The construction of the experiment is an embodiment of those models. These models are then algorithmically abstracted into a computer simulator of the experiment called DELANA which is used both interpretively to construct "the physics" and diagnostically to determine the functionality of individual detectors within DELPHI in terms of the models used to construct the machine is the first place. This is then used to construct a computer simulator of "track reconstructions", "particle momentum", "particle energy", "particle polarisation", "particle type", etc., on the basis of a "raw data" output which consists of voltage peaks, time signals, and detector cell identification numbers. Novel experimental physics is not simply hypothesis testing or theory falsification; it is a technological and theoretical ongoing process in which observations, models, expectations, and techniques are developed simultaneously in the context of making the experiment work as an experiment. Thus the process of modelling is one which is a two-fold process within the context of developing stable experiences and stable technical procedures, with the aim of constructing stable communicable objects. Pickering, like Gooding, emphasised the interplay of models, observations, and instrumentation that occurs in real experimental work (as opposed to the imaginary experiments of certain philosophers of science). They both highlighted the pragmatic character of this process and identified the technical practices, instrumental modelling, and phenomenal modelling, which interact with each other as the working experimenters attempt to construct stable scientific solutions which are perceptible and intelligible to both the experimenters and the wider public. Gooding observed (1990, p.254) that "[Faraday] did not respect a neat distinction between contemplative, theoretical aspects of practice on one hand, and instrumental and material practice on the other." This is also evident in the experimental work at Lancaster and CERN.

Models allow for human imagination, reasoning, argumentation, negotiation, visualisation, and intuition, to be active in bringing "the invisible world of causes" into the public realm, by making "it" manipulable, perceivable, and conceivable, in terms of the familiar objects and relations already within the public realm. Experimentation using models allows "the novel" visualisable, intelligible, and

[18] Such a device is called a Josephson Junction. Its function is to trap heat, described in terms of contained electronic energy levels, within a loop at specific temperatures. The choice of this device is based on a model of how it works. Such devices are also the subjects of research projects in their own right.

communicable, in terms of what already exists in the public realm. This use of modelling connects perception, imagination, and intuition, with the "the invisible world of cause" via technical manipulations and comparisons. Such a model is constructed through processes of induction and deductions based on the continually developed interconnections between unfamiliar and the familiar. This process even also uses abduction to act as analogical reasoning tactic in the proposal of new "working hypotheses". The inductive aspect of modelling allows the development of increased generalisation and abstraction moving towards the imagined and templated achievement of the ideal knowledge of *techne*. The deductive aspect allows the generalised and abstracted model to operate at the level of the particular in terms of possibilities. The abductive aspect allows the model to be analogously modified and re-directed by tactical guesswork. It is these inductively, deductively, and abductively, directed move between the general and the particular which allows analogy to operate between mathematical abstraction (in terms of a set of formal equations through which a more complex series of equations can be derived by setting parameters and utilising mathemtical techniques) and the particularity of the experiences of the physicists. It allows the experiences of physicists to be translated into different contexts.

Models have an intelligibility requirement that limits the form of a model to be meaningful and articulated. This means that models have to be constructed in familiar terms, which can be expressed in public language. This requirement constrains the model in terms of the model users' social conventions of language, and also opens up considerable interpretive ambiguity and freedom within those conventions. It is this interpretive ambiguity which opens up a space in between the abstract generalisations and the particular experiences which are continually fedback into one another in innovative ways. It is this space which both requires and allows negotiation and speculation to operate in experimental physics. From any experiences there are inductive pluralities that can be made depending on which essential features are selected. From any deduction there is considerable space for disagreement on whether or not it has been deduced correctly, on the premises involved, and on the applicability of that general model to this particular situation. There are always alternative abductions that can be made. At all stages of the modelling process, whether in construction or application, context-sensitive interpretations are involved. The success of an analogy in scientific work is rhetorically supported by reference to its usefulness rather than its truth, on the basis that "it is a model which works", and it is valued according to its pragmatic, or instrumental, value in the process of ongoing scientific work. It remains techneic, situated in the context of developing and tentatively evolving practices, apparatus configurations, and skills, but by virtue of its instrumental success is treated as if it has some epistemic correspondence. How does this happen?

Models, being based on analogies, are based on similarities, likeness, and are considered to be approximations of the phenomenon in question. This approximation allows a model to be treated as if it is approximately true in terms of having a likelihood, or probability, of being true. When a model is used in an argument for its truth based on it being probably true, or close to the truth, then such an argument is a *probabilistic argument.*[19] Probabilistic arguments require attendance to the already established beliefs, assumptions, prejudices, and opinions, if the arguer is to be successful in establishing the analogy as probably true, because they are attempts to establish a similarity, a likeness, in terms of the familiar and already accepted. In order to secure a model as an approximation of the truth it must be connected with the already established conventions of a community. This involves using imagery, metaphors, assumptions, predispositions, and values, which the community already has in order to present the enthymeme as convergent and coherent with the community's conventions. In Kuhn's terms, such an argument must be made within a shared paradigm and there would be a set of exemplar arguments that would have a high chance of working. By cohering with already established conventions, the argument has the character of a "naturalistic" argument; the community is more likely to accept what is possibly true as probably true, and what is probably true as true. The success at achieving this depends on the credibility of the scientific group making the argument, the perceived appropriateness of the analogy, the inspirational quality of the analogy used, the perceived utility of the model, the perceived difficulty (and risk) of refuting the analogy, and the intelligibility of the model. These dependencies all are established in relation with social agents. To establish a model requires integrating it within the conventions of these social agents; it involves bringing together these agents into coherent acceptance. This requires widespread distribution through credible media and also the skillful refutation and avoidance of any criticism.[20]

Measurement is an essential constraint placed upon models in physics. A model can be constructed out of visual, verbal, and mathematical analogies but in order *to qualify as a legitimate model in experimental physics it has to facilitate the derivation of measurable quantities.* This constraint means that the possibilities available for any particular model are limited by the physicists' expectations of measurability. This expectation is constructed according to expectations of cost, in terms of credibility risk and available resources, and perceptions of the limitations of available technology. The expectation of what is measurable is decided in reference to the already established labour processes, the economic support available to the group, and the conventions of measurement. This expectation of measurability enframes the available choices of models to be consensually commensurable with already established practices, techniques, and technologies. It is in relation to this axis of commensurabilty that the perception of

[19] Aristotle termed arguments of this type as enthymemic arguments. See Aristotle's *The Art of Rhetoric.* These are similar to syllogistic arguments, from which *episteme* could be reasoned, but instead of deducing the necessarily true these arguments construct the probably true. This construction involves the rhetorical skill of knowing how to persuasively manipulate one's audience and discourse. It was a *techne.* Contemporary writers have dealt with the subject of rhetoric in science. For examples see Gooding, et al., (1989); Fuller (1993); Billig (1987).

[20] As Latour and Knorr-Cetina, as well as Heidegger and Gooding, have pointed out, when making choices regarding what to put into a publication, and what not to, scientists already pre-empt possible criticisms to their results. This means that scientists are engaged in the public acceptability of their work when making their choices about the direction of that work.

measurability and manipulability is constructed as a perceived functionality of the available machines. It is this perceived functionality which acts as a constraint upon theory and practice.

"Natural phenomena" in experimental investigation are *reduced* to exoframed performances and, therefore, the object of experimental investigation is itself an analogy, a model, of the "natural phenomena" under investigation. Empirical experience is defined within experimentation; there is a technological constraint upon the form of any models used and what the possibilities of use could be. Furthermore, this technological constraint reduces what the form of a scientifically demonstrable ontology could be. Physicists will not consider any ontological description to be empirical unless that description has been produced within and validated by the technological context of experimentation. The ontology is technologically enframed and *episteme* is disclosed, *in advance*, by *techne* as an ideal. This technological enframent extends to visualisations, interpretations, conceptualisation, and mathematical abstractions. A model is invalidated if it cannot be subjected to experiment and it must remain within the boundaries of the technologically manipulable and demonstrable context. Thus the natural properties associated with "copper" are those, and only those, properties that can be mechanised and repeated within a technologically enframed model. When these properties are taken *to be* the "natural phenomena" the experiment *replaces* them with model constituted in terms of a set of machinable mathematical functions, stable interpretations, and related visualisations. By doing this, the physicists are taking the model *to be* the phenomena and are using the model metaphorically by treating the technologically constituted model *as* the natural phenomena. The model has replaced the phenomena through mathematical projection, in Heidegger's sense. The situation in ULT physics, or HE physics, is even more ambiguous because we are in a situation where *our only experience* of the phenomena occurs in the laboratory. There are no experiences of entities such as "AB-boundaries" or "tau-leptons" that occur outside the highly technological environments of the production, detection, and modelling context. As such these machines do not straightforwardly constitute metaphors because they do not replace the phenomena but, constitute the phenomena. This physics has the reverse situation where the "natural phenomena" are metaphors for the machine. The machine is replaced by "natural phenomena" and as such the latter is a metaphor for the former.

A metaphor is usually defined as a "deviation from normal meaning" and consequently is defined in relation to conventional usage. However, a notion of "normal meaning" is extremely difficult to define and maintain. There is a considerable ambiguity involved in the use of words like "normal", "deviation", and "convention". Especially when it is pointed out that the usual definitions of metaphor in terms of a deviation, a substitution, a transposition, a movement, or a replacement, of the proper usage of a word with another word, is itself a metaphor.[21] Not only do we have difficulty in establishing a stable definition of the words "proper", "normal", or "literal", but we also do not have a clear literal definition of the word "metaphor" either. This results in ambiguity when dealing with metaphors and literalness to the extent that

[21] This was pointed out by Paul Ricoeur in *The Rule of Metaphor*. Trans. Czerny et al., Routledge & Keegan-Paul, 1987, chap. 2. The term "metaphor" and its definition was coined by Aristotle. See *The Poetics* 1457b6-9.

we cannot be certain whether we are using any word, model, or image, metaphorically or literally. We can only appeal to conventions and habits. So how can we analyse the metaphorical substitution of "the model" and "the phenomena"? Let us start with similes. At the level of similes there is still some ambiguity about what constitutes a simile and what does not. At least we can agree that similes operate by making appropriate comparisons between members of distinct kinds. " Jack is as hungry as Jill" is not a simile whereas "Jack is as hungry as a horse" is. However, the notions of "distinct kinds" and "membership" are themselves both problematical and controversial. We can appeal to conventional notions of "kinds" and sets of conventional similes, or speech habits, such as "I am as hungry as a horse", or "You are as big as a mountain", but we find that substituting similes does not necessarily work as well. For example, "I'm as hungry as a mountain" does not work, whereas you are "You are as big as a horse" does. We find that not only do our similes need to be an appropriate juxtaposition of members of inappropriate kinds, i.e. you and a mountain, but there also needs to be appropriateness at the point of similarity, hunger or bigness. At the level of simile we are seeking appropriateness in the form of a vivifying, illuminating, and exaggerated, likeness, rather than a matter of fact comparison. It is a caricature. Are metaphors similar in this respect? The ambiguity of metaphorical usage is heightened because we are not making a comparison between "the Sun" and "Apollo" but rather superimposing one over the other. This is a substitution between incongruous and incompatible meanings if we take them as being definitely equal. A metaphor preserves the sense of "the Sun" not being "Apollo" whilst being taken as "Apollo". A metaphor involves equating the previously unequal whilst preserving the sense of their inequality and simultaneously treating one as the other. In the case of experimental physicists' use of metaphorical exchange between "the model" and "the phenomena" there to is the sense of their inequality whilst they are simultaneously being treated as interchangeable. The model is both taken to be the phenomena and also is not the phenomena. By using a model as a metaphor, physicists are able to treat the model as the phenomenon, replacing the phenomenon with the model, whilst distancing themselves from any commitment to that equation by maintaining that their model "is just a model" and is not identical to the phenomenon. The use of models as metaphors brings novelty and invention into experimental physics by allowing transactions between distinct contexts.[22] In experimental physics, metaphors allow the transference of technological objects between distinct machine-families and machine-kinds. For example, Morpurgo, by moving from an analogy to a metaphor, was able to construct an experiment to measure free quarks by using Millikan's oil drop apparatus as a template. A template allows physicists to use models to transfer metaphorically across machine-family boundaries by using models from analogous projects as templates. It allows them to tentatively explore the possibilities and actualities of the experiment and its meaning, without any certain knowledge, utilising the novelty and invention of the model metaphorically in order to secure it as a plausible approach to making the phenomena intelligible. It also allows the possibility of novel machine hybrids. In this sense, modern physics does not differ from poetry in that it generates new ways of seeing aspects of the world through

[22] This general point about metaphors was made by Richards in *The Philosophy of Rhetoric.* New York. 1965, p.94.

metaphorically facilitating, via a sense of appropriateness and intelligibility, a transformation of convention by bringing together heterogeneous technological objects.

Despite his lack of formal mathematical training, Faraday's electromagnetic field diagrams are constructed through technographe that he invented. They provide, within the context of a hermeneutic system developed by Faraday, the means by which geometry of electromagnetic field strength could be drawn and visualised. The development and use of this non-Euclidean geometry in physics shows the flexibility and creativity of technographic inscription. It permits the mathematical projection of novel construals and exoframes over the techno-phenomena of experimentation in such a way as to facilitate creative mappings between manipulative innovations in the design, construction, operation, visualisation, modelling, and interpretation, of machine performativity. Furthermore, it allows an intimate and revisable connection between theoretical and experimental practices whilst both are situated within the "technological framework" of research. Thus, for Bachelard, "the poetic art of physics is done with numbers, with groups, with spins."[23]

The poetic art of physics is a techno-poetics in which the *technographe*, pictures, models, and metaphors, of experimental imagination are physically embodied, through manipulative practice, in the mapping out of the contours of the interactions between human interventions and machine performances. It is akin to making an automaton from other automata and situating it within a world-picture. If we consider the case of the ULT physicists use of "superconductivity" to model "cosmic strings" then we can readily see the techno-poetics of experimentation. What is the metaphor here? It is through the juxtaposition of two trajectories of techno-poetics, the poetics of quantum fluids and those of cosmological topologies in the inflating manifold of the quantum flux of space-time, that the poetics is technically operational. Two previously distinct clusters of techno-phenomena are reflected against each other and one is presented as a model of the other. The metaphor is the substitution of the contours of the ULT physics interactions for the theoretically simulated exoframe of dark matter cosmology. The metaphor is the substitution of one technical trajectory for another; it is a techno-poetics of technique itself. It is in this sense that experimental physics is a poetical and performative art. This metaphor opens the aloof world of cosmological technographics (currently accessible to the human hand only through the use of pen and paper, and the computer keyboard and mouse) to the cluster of technological objects available to the ULT physicist. The transdicted invisible dark matter remnants of creation (something beyond perceptual acquaintance or "direct" experience, but used as a corrective to explain the existence of galaxies) come ready to hand through the techniques of ULT physics. Such a project is beyond the "rigors" of positivism! The experiences of digital outputs and technographic computer simulations of the performance of ULT cosmological experiments are techno-poetical disclosures of events that allegedly occurred billions of years before the Sun was born and, allegedly would be evaporated, without trace, by the sizzling heat of a snowflake. There is nothing immediately sensory about such disclosures. They are transdictions designed to solve the cosmological absence of the theoretically required number of visible galaxies. The "mechanisms"

[23] Quoted and translated in Tiles (p. 66).

disclosed through the ULT experiments are substituted as proposed mechanisms in operation to explain the animation of their instrumentation and computer outputs. The vibrations of the thin wires submerged in the near nothingness of superfluid He-3 are poetically transdicted as a form of "reverse engineering" which attempts to reconstruct the performativity of the machine in terms of the invisible interactions between quasi-particles, cooper-pairs, and energy gaps. It is then used as a working model of the motion of dark matter across empty space. The "invisible" is made visible through the metaphorical substitution of another "invisible". How could we not see the poetry of this?

As producers of metaphors, physicists are engaged in directed creativity towards making aspects of the world intelligible. Physicists do not (at least yet) possess the *techne* and *episteme* to claim certain and complete knowledge. They should not situate these new ways of seeing as objectively corresponding to something "out there", but they can claim that they are genuinely engaged in attempting to make parts of the world intelligible in novel and interesting ways. However, what they have missed, through familiarity, is that these parts of the world are made. In this respect physicists are engaged in a very human pursuit that is located, anchored, and directed from within a world-picture. A picture, as a metaphor, can only be understood if it is constructed by using culturally familiar pictures.[24] It was only in virtue of being anchored, located, and directed, within a cultural background that physics has been able to create and disseminate the poetical "mechanical world-picture". Metaphors allow the utilisation of present cultural pictures and technological objects in novel and unpredictable ways but are also bound up within the culture from which they emerge. Metaphors allow a disordering and ordering of cultural pictures and technological objects in such a way as to say something about one thing in terms of another. Metaphors allow selections, emphases, suppressions, reductions, and organisations, of the components of novel subject matters to be made in terms of other subject matters. Metaphors are more than "dispensable graces and ornamentation" and are essential to the development of new ideas.[25] The development and evolution of language requires metaphors in order to be able to transfer usage and meaning across boundaries between contexts. It is for this reason that Leatherdale (1974, p.102) argued that metaphors are essential for language to develop and evolve in any contexts where novelty is possible. The evolution and development of language is essential for the purpose of describing novel phenomena. Metaphors are essential for the development of novel technical languages from established technical languages and ordinary language.[26] The metaphor is not only essential for the construction of scientific discourse based on models, by substitution of models for phenomena, but it is also essential if that discourse is to be intelligible in terms of allowing the unfamiliar to be articulated in terms of the familiar.

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[24] This general point about using pictures as metaphors was made by McCloskey in *Metaphors*, Mind, 73, 1964, pp.215-33.

[25] This point was made by Black (1962, p.44).

[26] This point was made by E.H. Hutten, *The Language of Modern Physics*, London, 1958, p.84. The necessity of metaphor for the development of abstract and intelligible scientific language was also argued for by Black (1962, p.242).

However, when we begin to lose the sense that what has been made equal is not equal, when we loose the sense the "the Sun" and "Apollo" are not the same, then our metaphors cease to be metaphors and become literal truth claims. How does this happen? The strategy of rhetoric is to establish something as plausibly true in terms of the current conventions. This occurs in relation to current perceptions, beliefs, standards, values, presumptions, dispositions, assumptions, prejudices, etc. However, if a metaphor is continually used it becomes part of our available cultural stock of metaphors with appropriate contexts for use. When these metaphors become habitually and conventionally established within our language then they often are treated as if they were literal expressions. Once this occurs then there is an established and accepted literal object in the world for potential use in future metaphorical innovation. This provides literal objects for the background against which our metaphors are emergent. All theoretical cognition takes its departure from a background of language use that precedes the theoretician.[27] The transformation of the metaphorical innovation of language into literal usage is a transformation of the background of conventional language usage available for future transformation. Literalness is a sedimentation that occurs through practical and concrete language use. As such it is always determined within contexts of agency. The meaning of words occur in respect to practices and goals. Given a plurality of modes of human agency, literal and concrete usage is supported upon a pluralistic "ground" of conventional usage and innovative metaphors. The development of novel physics is bound up with a mode of being-in-the-world that can not be divorced from the cultural background that makes that mode possible. This cultural background gives modern physics its reality. The metaphorical use of pictures and technological objects is an extension of this cultural background and, as a consequence, it is an extension of reality. Physics is a mode of agency directed towards the innovative production of models and technological objects by using metaphors to transform and extend the reality that it is making. This involves the poetical and rhetorical use of metaphors in constructing pictures of Nature and also the innovative use of technological objects metaphorically across contexts of production. The reality of physics is brought forth into Being. It is in this sense that physics participates in *poiesis* and "world-making", as well as in the sense of providing the world with world-changing prototype machines (such as the electric motor and the atomic bomb) which the physicists "brought into being". As Nelson Goodman put it,

"What I have said so far plainly points to a radical relativism; but severe constraints are imposed. Willingness to accept countless alternative true or right world-versions does not mean that everything goes, that tall stories are as good as short ones, that truths are no longer distinguished from falsehoods, but that truth must be otherwise conceived than as correspondence with a ready-made world. Though we make worlds by making versions, we no more make a world by putting symbols together at random than a carpenter makes a chair by putting pieces of wood together at random." (1978, p.94)

Truth on this account is a form of truth that cannot be divorced from the beings for whom it is a truth without making it unintelligible. It arises as truth through a mode of agency and is *disclosed through*

[27] This point was made by Cassirer in *Language and Myth*, New York, 1946, p.28.

making it into a disclosure. It is brought-forth as truth. It is *aletheia* and, in Heidegger's sense (1977a, pp.11-3), discloses the way that experimental physics belongs to bringing-forth and *techne*. The establishment of belief occurs when models are taken literally instead of metaphorically. This substitutes a model as a phenomenon. The *techne* induced and abstracted from the ongoing productive practices of experimentation, and is disclosed as *episteme*. This facilitates the removal of that knowledge from the context of working practices and social agents through which it occurred. Once this has been achieved then that knowledge can be presented as "abstract general principles of how Nature works"; presented as yet another confirmation of the mathematical projection. It is through taking literally the metaphorical substitution of mechanistic models "of Nature" for the mechanistic techneic modelling process that allows the machine performances and manipulative procedures of the experiment to be dropped from physicists' accounts and replaced with abstract mathematical "Natural Laws" and causal mechanisms. It is due to this literalisation and abstraction that experiments can be seen to test hypotheses, falsify theories, and that the phenomena in question are presented as the product of a set of "natural mechanisms". The metaphor of "natural mechanism" has been established in our culture for at least 400 years and is the cornerstone of experimental physics. As I argued in chapter 2, the establishment of experimental physics was simultaneously the rhetorical establishment of the literalness of "natural mechanism" and the transparency of experimentation as a means of disclosure. The establishment of the method of experimentation as a road to truth was only possible because of the metaphysical precepts of mechanical realism. Techniques and machines could be treated as transparent means to the truth about natural mechanisms. The discourse of physicists could be then presented as directly reading the Book of Nature rather than writing it. Gooding argued that Faraday's aim was the publication of his discoveries in a form that could be communicated to the public. The wider social context informed Faraday's work and shaped the construction of his "discoveries". From Faraday's notebooks Gooding has been able to show that in transference from the local context of the laboratory to the wider public sphere, Faraday's procedures became transparent. Faraday successfully transformed his experiments into "observable phenomena" by transforming months of experimental work and highly complicated conceptual, perceptual, and technical manipulations into a single paragraph of published text. Latour and Woolgar described how the work of scientists is the transformation of modalities into unqualified and unconditional facts. They described the work of experimental scientists as a process of securing fictions as literal truth based on the situating of a publication within networks of allies and actors which disseminates scientific facts. The acceptance and criticism of scientific writings are situated within interplay between the credibility of the experimenters in question and the financial costs of experimental replication and falsification. Scientists have to balance the risk and investment of any experimental work that they are considering. In the process of constructing scientific writings experimental apparatus are "inscription devices" and are black-boxed.

Scientists very rarely invest their time, resources, and reputations, trying to falsify or replicate the work of others. Shapin and Schaffer (1985) described how Boyle managed to use literary technologies to make it possible for others to witness an experiment by proxy, as if the reader had performed the experiment, even though one would not have been able to replicate the experiment from Boyle's accounts. Collins (1985) argued that even when replication is attempted it is far from a straightforward technical task. There is often considerable controversy as to whether an experiment has been built and operated correctly. By considering examples from parapsychology and graviton physics he shows that there are highly significant social factors at play during the attempted replication of an experiment, which determine its success or failure. Innovative modelling, developed in the process of making the work of making material practices intelligible, is a metaphorical process that is used rhetorically and poetically. Not only is the physicist *homo faber* and *homo narrator*, s/he is also a techno-poet, innovator, and persuader.

The Art of Physics:

Ellul elucidated the difference between premodern craft practices and modern industrial technology.[28] The latter drives towards the creation of new instruments, in response to new needs, whilst the former continued by extending, refining, and perfecting the same means to achieve the same ends. The craft base for premodern societies was a consequence of their unchanging stability whereas modern societies are inherently unstable and constantly changing. Modern experimental physics operates upon the boundary between these two modes of production. It is both radically driven towards novelty and is conservatively attendant to its own self-perfection and refinement of well established means. In Heideggerian terms, modern physics is both bound-up with *Ge-stell* and *poiesis*. It is destined to order itself as standing-reserve for future work and brings beings into the world *for their own sake*. The "magnetic field" is both a technological object available for future work *as a tool* and is also an object for reflection *in its own right*. This two-fold character of the objects of physics is a manifestation of the two-fold character of physics. Physics operates across both the "premodern" and "modern" spheres of crafts and industrial technology. It is a bridge between the two. Modern experimental physics has its origins in the craft practices of the sixteenth century and provided the conditions for the industrial machinery of the nineteenth century. The mechanical realist precepts made this bridging possible. The "natural mechanisms" disclosed by experimental work could be taken to be truths *and* potential instruments for the ongoing trajectories of research. However, when Ellul (1964, p.74) wrote "the search [for efficiency] is no longer personal, experimental, workmanlike; it is abstract, mathematical, and industrial", he did so without a close inspection of the technical practices of experimental physics. In experimental physics the search for efficiency is personal, experimental, workmanlike, *and*, it is abstract, mathematical, and industrial. If spontaneity and chance are eliminated by the technical imperative (as Ellul argued that they are) then experimental physics can not be circumscribed by technique (as Ellul defined it). Without spontaneity and chance there is no space for discovery and innovation. It is for this reason that experimental physics must remain on the border between craft practices and modern technology. Furthermore, the performativity of the objects of experiments can not be determined in advance (otherwise there would not be an experiment at all). The underdetermined character of the technological objects studied in experimental physics, as

[28] As discussed in chapter two above.

objects of research, lends research a need for the innovative attentiveness of the "know how" and skills of the experimenters as craft practitioners. It is this need for innovative attentiveness and craft practices which makes experimental physics an art. This is a necessary condition for experimentation because, as an art, experimental physics allows a dialectical variability, in the construction and performance of an experiment, which is a condition for being an experiment at all. If experimental physics were to be a purely industrial and mechanised process then it could not be experimental. It is the underdetermined character of the objects of research which provides physics with a pre-industrial character because the objects of experiment need to be stabilised, in terms of mechanical and repeatable performances, before they can be repeatably assembled and mechanically integrated into industrial production. Once this has been achieved then the performative character of the objects has been determined and, consequently, is no longer of any experimental interest. For example, the electromagnet started as an underdetermined object for experimentation in the work of Faraday *et al.* but, in contemporary physics, it has been stabilised as a technological object to be used, as a determined and repeatable performer. It is a component in the cooling process in the experiments performed by the Lancaster ULT physics group on the superfluid properties of He-3, or as a component in the focussing of electronic (or positronic) beams in the CERN experiments on the properties of fundamental particles. The performances of electromagnets have transformed from being the end of research to being a means for research into the performances of other objects. The connection between *poiesis* and *Ge-stell* is premised upon the conception of change as being the product of the exercising of a natural mechanism. Thus the *productive* aspect of physics is the disclosure of mechanisms as *standing-reserve* for *Ge-stell*, whilst the *poetical* aspect involves situating these disclosed mechanisms within a world-picture. The *Ge-stell* aspect of physics is the challenging of *poiesis* to bring-forth mechanisms for the sake of disclosing them. Experimental physics is artistically and instrumentally situated between reiterated cybernetic feedback loops between the production of intelligible information as an internal good and as a technological object for future implementation.

The strata of machine-families provide physics with a technical-material infrastructure that is its standing-reserve as a technical background and concrete reality. The technical-material infrastructure is a connected cluster of techniques and machine-families described in terms of an ensemble of fundamental mechanisms operating upon a specific class of materials (defined in terms of their technological performativity) according to mathematical laws. In physics, technology legislates which practices are taken to be efficient and rejects the rest. Mechanical realism allows the assumption that efficiency is the fundamental principle of Nature. Newton's Third Law of Motion, The Conservation of Energy, The Second Law of Thermodynamics, and Mach's Principle of Least Action, are exemplary products of this assumption. The specification of "a universe" as the object of technoscientific activity is the metaphorical substitution of the techneic knowledge of machine performativity for the epistemic knowledge of natural "efficient" causes. As both of these kinds of knowledge are ideals then the whole final object of physics is the ambiguous metaphorical inter-changes between two imaginary ideals. Mechanical realist metaphysics provides a means by which the contingent human *tactics*, models, and practices, can be eliminated from the final account. The "know why" questioning of scientific questioning is enframed by the question of why something works and, consequently, it is reduced to the "know how" causal account of an ideal and unreachable *techne*. Just as one becomes a builder by building so one becomes an experimenter by experimenting,

CHAPTER 5:

THE ANVIL OF PRACTICE:

"Hephaestus, the God of Fire, has become the supreme master of the world. His furnaces are roaring. He has dispelled the clouds of Asiatic mysticism which obscured his native mountain. He has girdled the world with hoops of steel. In plain unmetaphorical language this is the age of science, of machinery... Every weapon, every machine is the embodiment of human thought and purpose. The user adopts that thought and purpose, and behold - the machine has found its soul."
E.E. Fournier D'Albe, 1962, p.1

"Our modern worship of technique derives from man's ancestral worship of the mysterious and marvellous character of his own handiwork." Ellul, 1964, p. 24.

Modern experimental physics is directed by the "how does it work?" question. By directing research towards the identifications of the "workings" of that which causes the phenomenon in question, modern experimental physics equates "the real" with "the mechanism". Thus modern experimental physics requires a tri-partite ontology: (1) what is moved (the object); (2) what moves it (the mechanism); (3) what governs or describes that movement (the law). By presupposing mechanical realism, modern physics operates upon a conception of the unity of its object (Nature), a unity of its means (the methodology), and, consequently, is able to present itself as a unified science aiming to disclose natural laws. The ontology of the part of the world presented by modern physics as Nature, the complex of machine-families, has only extended itself. The tri-partite ontology of physics has remained invariant in its structure throughout this extension, and its content only varies according to which particular machine-family member (with its associated mechanisms and laws) is under investigation. What enables us to build machines? This question is a central question for both realist and constructivist positions. The realist will claim that acting in accordance with "the laws of Nature" will enable us to build machines. The constructivist will claim that machines are passive objects that only achieve their functionality from human agents, social organisations, conceptual frameworks, networks, or rhetorical discourse. For example, on Bruno Latour's account (1990), machines are quasi-objects used to tie together social networks. Andrew Pickering presented an alternative constructivist interpretation in *The Mangle of Practice* (1995). He termed this as a posthumanist interpretation in which the results of experimental physics emerge from a dialectical relationship between "human agency" and "material agency" that occurs on the interface of machine performativity. His interpretation of modern experimental physics is that it is a performative and productive process. Pickering characterised modern experimental physics in terms of social labour processes of material practices that are transformed in response to the agency of the materials that experimenters work upon. There are many points of similarity between Pickering's position and my own. In this chapter I shall discuss the merits and flaws of Pickering's thesis. This will complete my groundwork for the development of an account of modern experimental physics as a performative, agential, and technological process.

The Mangle of Practice:

Pickering, like Marx, Lukacs, Kuhn, Latour, Bachelard, Bhaskar, Hacking, Ellul, Gooding, Mueller, Heidegger, and the members of the neo-marxist Frankfurt School, identified knowledge based upon emergent material practices to be a product of a "historical trajectory". Pickering (1995, p.3) wrote that "...an irredeemable historicity of scientific knowledge (and culture in general) in what counts as knowledge now is a function of the specific historical trajectory that practice has traced out in the past". Furthermore, like Marx and Ellul, *et al.*, he argued that history should be written in such a way as to place "the Industrial Revolution" in the place of "the Scientific Revolution" in the history of science. For Pickering, the material practices of human agents were central to his understanding of experimental physics. He used the following examples: Glaser's development of a bubble-chamber (pp.39-63), Morpurgo's search for free-quarks (pp.72-99),[1] Hamilton's invention of the quaternion system (pp.135-43), Noble's study of the incorporation of numerically controlled machine tools at the General Electric Aero Engine Group plant in the 1960s (pp.159-76), and, the work of the US Radiation Laboratory during WWII on the development of radar for military purposes (pp.236-40), for the purpose of elucidating his metaphor of "the Mangle". In the following analysis of this metaphor, I shall restrict my discussion to Pickering's interpretation of Glaser and Morpurgo's work.

In traditional approaches to agency the concepts of agency and intentionality are bound up with one another. It is assumed that only human beings have intentions, and therefore only human beings can be agents. Pickering was critical of this approach. He agreed that only human beings have intentions. However, he argued that "material resistances" to human intentions, and the modifications made to intentions in response to those resistances, which he termed as "accommodations", can only be understood if we consider materials to be agents. He argued that the problem with humanist sociological studies of science is that they tend to *reduce* scientific agency to particular modes of human agency. He maintained that these studies are more sociological studies of scientists than sociological studies of science. I agree with Pickering that sociological studies often present accounts of experimental apparatus as passive components of human agency. He cited Bloor, Barnes, Shapin, and MacKenzie as examples of this tendency[2]. Pickering argued that this reveals an asymmetry in

[1] On the controversy with Fairbank see pp. 210-12.

[2] He was also critical of Kuhn, Lakatos, Collins, and Hesse, because, he claimed, that they have assumed a "monolithic" scientific culture and that there is a general principle characteristic of all science. In my view, these criticisms are unjustified. Kuhn, Lakatos, Collins, and Hesse did not base their analyses on any such notions. Kuhn characterised science (mainly physics) in terms of collections of beliefs, values, assumptions, techniques, and practices, for given periods of time, and claimed that theories from different periods of time were incommensurable with one another. He did not provide any general principle by which these elements were organised. Lakatos characterised sciences, at given time periods, as collections of research projects without identifying any general principle by which the research projects were selected or conducted. Collins, following Hesse, characterised science in terms of the social ordering of conceptual nets but offered no general principle by which they were

sociological studies of science. Using the example of Glaser's attempt to "build a bubble-chamber", Pickering pointed out that Glaser had to find many different solutions to "the triggering problem", during the course of developing a working bubble-chamber that could detect "cosmic rays", because each proposed solution failed, one after the other, despite Glaser's expectations of success with each new solution. Pickering asked the following questions: if each of these "solutions" were socially constructed as "expected successes", and "the detection of cosmic rays in bubble-chambers" is also socially constructed, then, why should we see this sequence of failures? Where was the social causal factor here? Who was constructing the failures? Pickering argued that we cannot provide an intelligible account of scientific practice solely in terms of social construction theories because, as well as human agencies, there *must* be other agencies at work against which human agency can organise, and be organised, in interaction with. Pickering claimed that this is actually a single agency, which he termed "material agency". He defined material agency as "simply the sense that Glaser's detectors *did* things – boiling explosively or along the lines of tracks or whatever – and that these doings were importantly separate from Glaser." (p.51) Pickering's point was that the state of affairs, which arose through Glaser's relation with the bubble chamber, was something that was not under his control and occurred in the performance of the machine. He attributed the source of this to be "material agency".

Using Kreiger as support, Pickering argued that physicists deal with the world as a field of agency with machinic and material dimensions – the scientific world is "amply stocked with material agents". (p.7)[3] Pickering addressed the essence of experimental physics by focussing his description of what experimental physics *is* by what experimental physicists and materials *do*. He called this "the performative idiom". As he put it: "My basic image of science is a performative one, in which the performances – the doings – of human and material agency come to the fore." (p.21) Through both an analysis of the "internal performances" and the "external discourse" of science, Pickering attempted to "get a closer look at material agency". He claimed "that we should see the bubble-chamber as effecting a capture of material agency, as a particular combination of particular elements that *acts* in a particular way." (p.52) He argued that the interests and identities of scientific agents are *at stake* within scientific

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constructed. All of these analyses are consistent with the view that scientific culture is comprised of diverse cultural elements which are brought together in localised projects. Pickering's criticism seems to be based on a misrepresentation of their ideas. He was also critical of Gooding's (1992) studies of the experimental work of Faraday and Morpurgo, because Gooding, claimed Pickering (p.97 fn. 22), whilst emphasising agency in experimentation, only considered human agency and, by doing so, was "remaining faithful to the representational idiom". In my view, Pickering's criticisms of Gooding were unjustified. Pickering missed the point of Gooding's analysis. Gooding did not reduce scientific work to human agency but emphasised human agency in experimental work in order to make points within particular debates in the philosophy of science. Gooding *explicitly* argued that the empirical observability of "phenomena" depends on the inter-relation between activities and skills that have both material and social dimensions. Gooding argued that these material and social dimensions complement one another in making experimentation meaningful.

[3] Krieger, M., *Doing Physics: How Physicists Take Hold of the World.* Bloomington: Indiana University Press.

practices rather than "causal principles lying outside (behind, above) and explaining the extension of scientific culture."(p.64) He distinguished between resistance and Durkheimian constraint on the basis that the former occurs during the interaction between material agency and human agency, whereas the latter occurs within the human realm.

Pickering's analysis of scientific practice began with "intentionality". He defined intentionality as the setting of specific plans and goals that occur in the human realm. Once an intention to build a specific machine has been initiated human agency and material agency interact. Pickering termed this as "a dialectic of resistances and accommodations" in which machines are *intermediaries* between human and material agency. For Pickering, "[t]he machine ... is the balance point, liminal between the human and the nonhuman worlds."(p.7) The machine is the interface between human and material agency. In his analysis Pickering intended to produce "a performative image of science, in which science is regarded as a field of powers, capacities, and performances, situated in machinic captures of material agency."(p.7) This "field of machines" constitutes the established performativity of science – these machines' performativity is enveloped by the "human realm" through human practices such as skills and "whatever [is] required to set machines in motion and to channel and exploit their power."(p.16) Machine performativity and human performativity occurs simultaneously and, consequently, in experimentation, performativity is that of human-machine relations. The process of this relationship is one of "tuning", or feedback, of both human and machine performativity in relation to the other. It is through this process that both material agency is temporally emergent as "captures" and human agency is temporally emergent as "discipline" (or skills). Both "reciprocally and emergently define and sustain one another", remaining "constantly intertwined", and "interactively stabilized".(p.17)

In Pickering's analysis of experimental physics the notion of "temporal emergence" was central. But what does temporal emergence mean? For Pickering, this ultimately meant that "things just happen". As he put it, "there is no substantive explanation to be given for the extension of scientific culture... [i]t is the pattern... of open ended extension through modelling, dialectics of resistance and accommodations."(p.47) Pickering asserted that this "open-ended extension" was something which, in principle, could not be explained because "[n]othing substantive in scientific culture or anywhere else... necessarily endures through and explains the process of cultural extension; everything in scientific culture is at stake in practice; there is nothing concrete to hang onto there." (pp.111-2) He argued that material agency is "temporally emergent" only through practice because the "contours of material agency" cannot be known in advance and only arise as resistances to accommodations to previous resistances. (pp.53-4) In other words, material agency only arises as a result of scientific exploration finding new problems that arise when new machines are used to solve problems. Human and material agencies are both temporarily emergent through "a dialectic of resistances and accommodations" when they are capable of being stabilised. This stabilisation is produced as a result of a "constitutive intertwining" between human agency and material agency. This dialectic is what Pickering referred to as "the Mangle of Practice". Reality is continually, and dynamically, undergoing production through this dialectical process. For instance, using the example of Glaser's project, Pickering wrote that "[i]t is clear that Glaser *had no way of knowing in advance* that most of his attempts to go beyond the cloud chamber would fail but that his prototype bubble-chamber would succeed, or that most of his attempts to turn the bubble-chamber into a practical experimental device would fail but that the quenched xenon chamber would succeed. In fact, nothing identifiably present when he embarked on these passages of practice determined the future evolution of the material configuration of the chamber and its powers. Glaser had to find out, in the real time of practice, what the contours of material agency might be." (p.52, my emphasis)

It is practice that intertwines the contours of material agency with modes of human agency in such a way as to inextricably mix together material agency and human agency as mutually ontologically and epistemologically productive. As Pickering put it,

"I need to stress that the trajectory of emergence of material agency is bound up with that of human agency. Material agency does not force itself upon scientists. There is, to put it another way, no such thing as a perfect tuning of machines dictated by material agency as a-thing-in-itself; scientists, to put it yet another way, never grasp the pure essence of material agency. Instead, material agency emerges via an inherently *impure* dynamics that couples the material and the human realm." (p.53-4)

It is the machine that constitutes this coupling. For Pickering, the contours of material agency emerge as resistances to human agency; without human agency these contours would not exist. This was a central premise for Pickering's thesis because

"[t]he resistances that are central to the Mangle in tracing out the configurations of machines and their powers are always situated within a space of human purposes, goals, plans; the resistances that Glaser encountered in his practice only counted as such because he had some particular end in view. Resistances, in this sense, exist on the boundaries, at the point of intersection, of the realms of human and nonhuman agency. They are irrevocably impure, human/material hybrids, and this quality immediately entangles the emergence of material agency with human agency without, in any sense, reducing the former to the latter." (p.54)[4]

Human agency and intentionality are transformed and restructured throughout the process of trying to achieve the original intention. The scientist may, in the process of trying to succeed in achieving any original goal or project, end up succeeding in a different goal or project. Human intentionality is, in Pickering's terms, "emergently reconfigured in its engagement with material agency... because they are configured in response, as accommodations, to the resistances emergent through precise material

[4] It still seems to me that a realist could argue that this still allows the possibility that there are real, pre-existent, material causes that we can only be aware of when we perform certain practices and build certain machines which actualise them. Pickering did not provide an argument to counter mechanical realism. He made a judgement against it.

configurations."(p.54) Accommodations take the form of adjustments to intentions, adjustments to practices, adoption of alternative techniques, changes in the material configuration of the apparatus, or employing expertise as a resource. These accommodations transform the original intentions because they "can amount to a revision of plans and goals, to a revision of the intentional structure of human agency... Goals, then, have to be seen as subject to mangling in practice."(p.57) However, intentions, although transformed in interaction with material agency, remain with the human realm, because although these transformations produce an ambiguity between means and ends, "both means and ends are bound up in human intentionality"(p.57 fn.19). Pickering maintained that because both intentionality and choices of particular accommodations are bound up in the human realm, scientists creatively arrive at particular strategies of accommodation (p.58). Human intentions operate in "a field of existing machines" in such a way that the goals of scientific practice are emergent in relation to this field as they take advantage of "prior captures of material agency". It is this relationship between disciplined human intentionality and machines, in which both are mutually modified through "reciprocal tuning", which keeps human intentions "bound up and intertwined with" material agency.

Material agency is emergent in the form of resistances to human intentions which, in turn, are modified, transformed, as accommodations to material agency. This dialectical process is actualised when human beings construct a new machine and the material agency arises when human beings *passively* observe the response, the performance, of the machine. As Pickering put it, "As active, intentional beings, scientists tentatively construct some new machine. They then adopt a *passive rôle*, monitoring the performance of the machine to see whatever capture of material agency it might effect."[5] This is apparent in Pickering's analysis of Morpurgo's observations when he wrote "As a classic human agent, Morpurgo assembled his apparatus, switched it on, and then, surrendering his active role, stood back to watch what would happen – literally, through a microscope. Swapping roles, the material world was in turn free to perform as it would; the grains levitated and moved away from their equilibrium position when the electric field was applied." (p.79) Neither human agency nor material agency can be separated from one another nor reduced to one another. Pickering described this relationship in terms of a "struggle", or a "dance", in which both are "reciprocally and emergently intertwined".[6]

It is this dance, or struggle, which Pickering referred to by "the Mangle" metaphor. He used this metaphor to describe the goal-orientated and goal-revising dialectic of resistance and accommodation, that he took to be a general feature of scientific practice, by conjuring up the image of

[5] p.21 (My emphasis.)

[6] Pickering seemed to be claiming that the dancers only exist during the dance. At the end of the book he referred to this "dance of agency as the dance of Shiva" and there is the impression that Pickering did seem to suggest that this struggle or dance is eternal. I wonder to what extent this metaphor is a throwback to Pickering's "earlier incarnation" as a particle physicist. It is quite common amongst young particle physicists to make much of "the dance of Shiva" metaphor to express the way that the inter-relation and relative motion between particles, forces, and each other, can be observed, and even modelled, but still remains impenetrably shrouded in mystery and somewhat illusionary. I believe that Hindus term this dance of mystery and illusion as *maya*.

unpredictable transformations emergent as material and human agency are transformed and delineated. This metaphor operated within Pickering's analysis as a device that allowed him to articulate a universalisable account of scientific practice as an evolving field of human and material agencies, which are reciprocally intertwined in a play of resistance and accommodation.

Pickering's analysis presented a structure of scientific practice which has humans as intentional agents, material agents as "emergent brute resistances", and machines as the intermediaries between the two. The situation is one of continual feedback, in which, to use Pickering's terminology, the dialectic of resistance and accommodation is a *mutually* occurring inter-relationship between humans and materials that transforms both sides. This dialectic is primarily interactive and, therefore, intentionality *cannot* be assumed to be *straightforwardly* structured only within human agency. Although Pickering maintained that neither human nor material agency could be reduced to the other (humans are not materials, and vice versa) he also maintained that there is not any purely "human realm" nor "material realm". He could only define the poles of the dialectic negatively in terms of not being the other. Pickering argued (p.92) that resistances are "situated right on the boundary of the realms" and those accommodations work "impartially upon both sides of the material-conceptual divide." Pickering's analysis required and utilised, in order to sustain a concept of dialectic, a two-fold interactive unity. On one side we have human agency construed as "contours of the social" in terms of knowledge, representations, abstractions, concepts, intentions, and disciplines. One the other we have material agency construed as "contours of material agency" in terms of resistances. Both of these sides are held together, emergent through, machine performativity in terms of disciplined human agency and captures of material agency.

How did Pickering relate making machines and the knowledge of Nature? Pickering argued that conceptual and material elements are emergently arranged together through practice. These arrangements are then taken as "conceptual chains" and "linked" to representations. It is these structures of conceptual chains and representations that constitute articulated scientific knowledge. "The Mangle" brings conceptual and material elements together and interweaves them. Pickering made this point about Morpurgo's search for free-quarks when he wrote (p.69) "Morpurgo's practice was organised around the construction of *associations* or alignments between [material and conceptual elements] that would lead outward from his material apparatus and its performance into the world of articulated knowledge and representation." Pickering refused to make a sharp distinction between conceptual and material elements in the construction and operation of experiments. In the construction and operation of an experiment, the material elements are construed in terms of function within a larger ensemble of functions. However, the functionality of a material element is dependent upon how it is conceptualised within the organisation of the ensemble of functions in which it is situated. Each and every functional element within an ensemble of functions is simultaneously a material and a conceptual element.[7] Even if one were to take a part of a machine, say a bolt, and clank it upon a table to demonstrate its materiality, its "stuffness", then due to the demonstrative role of such a performance, the clanked "stuff" still has a conceptual element as an example of a material.[8] It is

[7] Gooding (1992) made this point regarding Faraday's experimental work.

[8] This is my example.

through this interweaving of conceptual and material elements that a representation of the experiment is allowed to be constructed in terms of framing the interactive stabilisation of human and material agency, because "such stabilizations involve a precise *framing* of machinic performance in relation to the conceptual structures with which they are linked." (p.69) Conceptual structures constitute a frame upon which articulate "external accounts" and representations of material machinic performances can be constructed. Pickering emphasised throughout his analysis of scientific knowledge that theories and representations constructed upon conceptual framing of machinic performativity are themselves only emergent through practice. As he put it (p.69), "scientific knowledge is sustained in extended representational chains spanning multiple levels of theoretical abstraction, and that alignments along such chains should themselves be understood as subject to, and the products of, mangling in practice."

Pickering proposed that scientific culture is a patchy, scrappy, disunity of diverse cultural elements in which scientific practice is nothing more than making associations between these elements. Technical knowledge, abstract laws, expertise, models, experiences, techniques, machines, concepts, etc., are elements, resources for mangling, within his analysis, that could not escape "the Mangle", and can not guide it. His analysis left nothing that can help us to make associations because it would have to be outside "the Mangle" and there is nothing outside "the Mangle". In his analysis there is *literally nothing that could enable us to build machines.* It is all just happenstance. We feed our intentions in, "the Mangle" transforms them, mixes up a load of cultural elements, and spits out a product as an element for future mangling. If that product fulfils our original intentions, or our transformed intentions, then that is simply a matter of good fortune. "The Mangle", as "a dialectic of accommodations and resistances", interacts on the machine interface between human and material agencies to produce "interactive stabilizations" as "temporal emergences" in the real-time of practice. These "interactive stabilizations" are the associations between the diverse cultural elements. But how are these "interactive stabilizations" produced in the real-time of practice? Pickering could not provide any general answer to this question. If he did then he would have undermined his own thesis because he would have provided us with a general principle, which would enable us to build machines. In other words, Pickering could not provide us with a general account of how "the Mangle" works; he could only, retrospectively, map out the mangling process in particular cases. He explicitly rejected the notion that there could be transferable skills, any general knowledge of machine building, experiences, or even guidelines, which could enable us to build machines. All of these are nothing more than elements for mangling; they do not shape the mangling process.

Pickering went further than this. He argued (pp.188-91) that particular interactive stabilisations, or associations of cultural elements, are, in fact, incommensurable with one another. For example, he argued that post-1970s and pre-1960s particle physics are incommensurable with each other.[9] He claimed this because these two phases, or regimes, of particle physics have a different collection of machines and instruments they consequently have a different machine performativity. In Pickering's analysis, a different machine performativity meant that the captures and contours of material agency would be different because the nature of the dialectic of accommodations and resistances will be different. For Pickering, it followed from this that they produce different

[9] See also Pickering (1984). sections 6.4 and 6.5

associations between cultural elements and therefore have different ontologies.

Unmangling the Mangle:

I agree with Pickering's claim that conceptualisations and representations of machinic performativity in experimental physics are transformed and produced by actually building and performing the experiments. I think that this is a fairly uncontentious claim. However, this raises some very important questions. How are the associations actually made? How is the framing constructed? How are representational chains constructed? How are these chains connected to theoretical abstractions? Pickering did not address these questions. His claim that "scientific knowledge should be understood as sustained by, and as part of, interactive stabilizations situated in a multiple and heterogeneous space of machines, instruments, conceptual structures, disciplined practices, social actors and their relations, and so forth."(p.70) This is central to my own analysis of experimental physics in this thesis. However, Pickering left more important questions unaddressed. How are "interactive stabilizations" achieved? How is "Nature" linked to the production of "interactive stabilizations"? Furthermore, Pickering did not provide any discussion of the way that scientific knowledge is fedback into other projects in such a way as to actually *inform* the scientists involved. For Pickering, knowledge was a product but never involved in the production process except as an element for mangling. He did not allow knowledge to actually guide the process of mangling in any way and consequently the development of technical know-how seems quite inexplicable. He went as far to say "that *nothing* – in Collin's or the scientists' sense – "enables" us to build machines: when we succeed in doing so, it is via a fortune passage through the mangle...". (p.102, fn.25) Why did Pickering reject the possibility that there could be something that enabled us to build machines? On what basis did he make such a judgement?

In Pickering's analysis, scientific thinking is described as a two-fold process of intentionality and modelling. This process of modelling takes the form of making analogies and metaphors. If we accept Pickering's premise that modelling is central to the practices of experimental physics, which is something that I argued for in the last chapter, then we can not sharply distinguish between conceptual elements and material elements within experiments because modelling is central to the construction, operation, and interpretation of experiments.[10] In his analysis of Morpurgo's experiment, Pickering pointed out that "[t]o move from observations of the response of the grains to an applied electric field to statements about the electric charges carried by the grains, Morpurgo drew upon his *interpretive account* of the MLE [Magnetic Levitation Electrometer], his conceptual understanding of how it functioned. The basic form of this was very simple, being given by the laws of classical electrostatics."(p.74) I agree that an interpretive account is required for this move. However, such an interpretive account is also required to make "observations of the response of the grains to an applied electric field". Models are implicitly involved in the construction of the apparatus, the development of operational procedures, and the making of observations. In Morpurgo's experiment we cannot sharply distinguish between conceptual, manipulative, and material elements, because all of these elements are interweaved in each and every stage of the experiment.[11] The material form of an instrument is

[10] This point was also made by Gooding (1992).

[11] This point was also made by Gooding (1992)

simultaneously a conceptual form; without this interweaving of materials and concepts there would be no instrument because instrumentality implies purpose. An apparatus is constructed and interpreted in terms of performance and production; it is constructed and interpreted as an ensemble of functions, theoretical significance, and technical procedures (i.e. turning a particular dial will change the electrostatic force upon a grain suspended in a magnetic field). I agree with Pickering up to this point. However, I think that Pickering utilised a distinction between "the material" and "the conceptual" which he maintained was untenable during "the real time of practice" and could only be made retrospectively using the reconstructed accounts of the experiment. Pickering's analysis was inconsistent on this point. Pickering (p.78) took the construction of Morpurgo's "material apparatus" as a starting point which then required a subsequent analysis of "how Morpurgo threaded his material apparatus into the field of articulated scientific knowledge and vice versa."

However, by doing this, Pickering was ignoring the extent to which the apparatus was already interweaved with pre-existing fields of articulated scientific technique during its conception and construction. What Morpurgo had to do was weave what he has learnt from constructing the apparatus back into the pre-existing fields of articulated technique and transform them. This shows that Pickering did not allow technology to guide action; it is a product of mangling, or an element for mangling, and nothing else. In my view, without constructing the apparatus in terms of pre-existing fields of techniques Morpurgo would not have had a starting point. The apparatus was an embodiment of a synthesis of pre-existing fields of techniques and also a means by which those fields could be transformed. Morpurgo did not begin in a state of innocence, with lumps of functionless "stuff" which he somehow assembled into a functioning machine, *and only then* related to a field of articulated techniques. At each and every stage of construction his choices of components, and their interconnection, were based on his current scientific background in such a way that the apparatus was already, at least partially, situated in a pre-existing field of scientific technique. As we can see from Morpurgo's own accounts his apparatus was a variant of, and comparable to, Millikan's already established oil-drop experimental apparatus to measure the electron's charge.[12] This was a reasonable strategy, within the terms of pre-existing articulated scientific techniques, because, by analogy, what Millikan had established about discrete electronic charge, Morpurgo could potentially establish about fractional electronic charge (the theoretical characteristic of quarks) and consequently use Millikan's apparatus as a model for an apparatus to search for free-quarks. The Morpurgo example offers an interpretation which causes problems for Pickering. Pickering neglected to attend to the extent that the "conceptual" and "material" elements were *already mangled* prior to constructing the experiment. Morpurgo's work did not consist in only mangling these elements further, though it seems that did occur, but it also consisted in *unmangling*, disentangling, the whole process into distinct elements of theories and techniques. It is this unmangling which allowed a "material apparatus" to be distinguished from "a theoretical model" and consequently work as an experiment to demonstrate the existence or inexistence of free-quarks by comparison (rather than correspondence). It seem that in order to understand scientific practice we need to analyse the way that it involves unmangling as well as

[12] *A Search for Quarks (a Modern Version of the Millikan Experiment): One Researcher's Personal Account*. Genoa. Mimeo. 1972. p.5-6.

mangling. Without unmangling the experiment into distinct "theoretical models" and "empirical observations" then experiments could not work as "tests" for the "correspondence" of models to facts. The question is: how do physicists unmangle the mangled? Pickering quoted a technical report about the effect of platelet separation on the gradient of the applied field made by Morpurgo, *et al.*,[13] in order to support his argument that "[a]t this detailed level of conceptual analysis, therefore, Morpurgo's transformations of the material configuration of his apparatus went against his interpretive account of it, and the success of the former led, in turn, to a further revision of the latter."(p.85) However, Pickering's construal of this technical report as a conceptual analysis is misleading because he ignored the extent to which concepts, formula, representations, and interpretations, in that report, are ambiguously interweaved in the analysis of the functional effect of plate separation on the behaviour of the apparatus. The identification and distinction of separate analytical elements in that report could only be done *reconstructively.* What technical reports, like Morpurgo's, show is that revisions of the interpretive account arise due to the plurality of possible choices available as to what are significant and important mechanisms within the application of any model. What Morpurgo's report shows is the transformation of his estimation of plate separation on the performance of the apparatus. It does not show any distinction between discrete elements in terms of conceptual analyses, interpretive accounts, and material configuration. It remains a report of technique and performance. These are still "mangled" at this stage of Morpurgo's work. The crucial distinction made in this report is between platelet separation functionality and MLE functionality and how the former effects the latter. It was only subsequently that Morpurgo was able to make an interpretive account in which theoretical conceptualisations and machine performances were sufficiently distinct to allow the identification of "spurious charge values" that were "a product of the apparatus" rather than "a natural phenomenon". Pickering (p.86) emphasised that there was a "three-way interactive stabilisation between Morpurgo's material procedures and conceptual analyses, interpretive and phenomenal, in which manoeuvres in the field of material agency played a constructive role alongside conceptual ones, and material performances and conceptual understandings guaranteed and underwrote one another, back and forth." However, in my view, Pickering actively and retrospectively identified those elements as constitutive of scientific work, whereas those elements were, during scientific work, components of one another to such an ambiguous extent, that the work of Morpurgo was that of producing a distinction between them; it is only after this work had been done that there could be said to be elements which were interactively stabilised. Contrary to Pickering's view, scientific work occurs in the face of mangled ambiguous plurality, rather than on a conveyor belt of cultural elements leading into the Mangle. The aim of that work is to un-mangle this plurality of possibilities into discrete, intelligible, and comparable elements. As such scientific practice is not "the Mangle" but rather an attempt at un-mangling it by using its methodology as a template for techniques.

Pickering was correct to identify the ontology of particle physics as the product of modelling machine performativity but he misunderstood the connection between distinct phases of particle physics. His claim that the pre-1960s and post-1970s phases of particle physics have *different*

[13] 'The Magnetic Levitation Electrometer and Its Use in the Search for Fractionally Charged Particles', *Nuclear Instruments and Methods*, 1970, 79: pp. 95-124.

ontologies and are incommensurable is only possible due to his positivistic conception of ontology. Such a conception makes particle physics unintelligible. The mechanical realist metaphysics underpins both phases of particle physics and allows both to participate in the disclosure of the same ontology. Both phases of particle physics share some of the same components (electromagnets and ionising fluids, for example) and the models utilised to interpret machine performativity shared some of the same functives (i.e. charge, spin, and mass). In order for these two phases of particle physics to be incommensurable they would have to be absolutely distinct and have nothing in common whatsoever. It certainly is evident that the Glaser bubble chamber and the LEP-ring at CERN are very different machines. However, they do share important functives such as voltage, current, magnetic field strength, momentum, energy, etc. If we look at the models of the post-1970s and pre-1960s particle physics, we can readily see that they both share common elements, such as differential calculus, statistics, algebra, arithmetic, SI units, etc, as well as common mechanisms, such as radioactive decay, electron and photon interactions, electron and positron production and anihilation, spin and energy levels coupling, virtual particles, etc. They also share common functives like charge, mass, spin, force, momentum, energy, half-life, etc. Both also utilise special relativity, Maxwell's equations, and the periodic table etc. Many of these elements were used to construct, operate, and interpret both Glaser's bubble chamber and the LEP-ring. Of course, many components of the LEP-ring, such as the barrel RICH[14] in the Delphi detector, and the CRAY supercomputer at CERN, were not available for pre-1960s physicists. However, does it follow from the fact that these machines were unavailable to pre-1960s physicists that the two phases of particle physics are incommensurable with one another? Contemporary undergraduate students often use cloud chambers, and bubble chambers, as part of their studies. Although much of the theoretical physics of the post-1970s is incommensurable with the pre-1960s (i.e. Quantum Electrodynamics, the electroweak interaction, Quantum Chromodynamics, etc.), in the sense that it utilises functives, technographics, and exoframes which have no place in the earlier physics, the converse is not the case because most particle physics postgraduate students have to learn the pre-70s theory before they can learn the post-70s theory. Both phases also use the same metaphors: particle, wave, track, spin, creation, annihilation, basic building blocks of matter, etc. It seems that even if we could say that pre-1960s particle physics is incommensurable with post-1970s particle physics it does not follow that the converse is true. However, the general models of pre-1960s and post-1970s particle physics share some common features (such as basic functives, the theory of special relativity, and mechanisms of material-particle interaction) and, at most, could be said to be *partially* incommensurable. However, I think that even this much would be going too far. The ensemble of machines used in both phases of particle physics are distinct, but related machines. They are related as members of the same machine-family because the post 1970s machines share components with the

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[14] Ring Imaging Cherenkov Radiation detector. One could say that the barrel RICH was partially incommensurable with post-1970s physics too, at least up to 1995, because the DELPHI physicsts and engineers could not get it to work properly all of the time, nor provide a complete account of why it would not work properly all of the time. However, the basic principle of this detector is to provide calometry of the ionisation produced by charged particles in a dense liquid and, at least in terms of its basic principle, is commensurable with the basic principle of a bubble chamber.

pre-1960s machines. Furthermore, computers are connected to the post 1970s detectors. These machines run reconstruction programmes that technographically represent the "data" as "bubble chamber" pictures of "tracks" on the computer screen.[15] These computers are part of the detector performativity. In terms of technographic presentation, there is little difference between a computer printout of a white circle with black lines, broken curves, and splotches, and a bubble-chamber photograph of a black circle with white lines, broken curves, and splotches. Nor is the basic particle physics used to interpret these images significantly different. Furthermore, the post-70s detectors, such as the CERN detectors, were hybrids between the liquid-based detectors such as the bubble chambers and the gas-based detectors such as the geiger counter. These two types were related through the mechanism of ionisation. This connects them in the CERN detectors as electronic devices. The DELPHI detector is, to put it crudely, not much more that a massive barrel of thousands of modified geiger counters and bubble chambers (each one is a detection cell), surrounded by a massive electromagnet. Each cell, when triggered, transmits a voltage peak, a time signal, and an ID number. That's all! Computers and reconstruction techniques do the rest. As a hybrid machine, it is a member of both the machine-families of the bubble chamber (cloud chamber, drift chamber, etc.,) and the geiger counter (xenon tube, arc lamp, etc.) connected by the ionisation mechanism. All three are connected with the electromagnetic machine-family. It is this membership of the same machine-family that provides the shared components of pre-1960s and post-1970s machines with transfactuality. They are linked historically and technologically as innovations of the same project (i.e. the physics of the motion of interactive particles in electromagnetic fields) that was projected using the same ground-plan (mapping out the connections between the geometry of kinds of events with the material conditions of those events). It is this link that allows the extension of the pre-1960s machines into the post-1970s machines to be presented by the mechanical realist as a process of disclosing ontological depth. The post-1970s machines are presented as allowing the exploration of a "deeper" level of the same reality disclosed by the pre-1960s machines. The mechanical realist metaphysics is foundational for both phases of particle physics to be phases of the same field of physics and, as such, are taken to disclose the same ontology. They achieve this unity through the projection of the methodology.

If we accept Pickering's argument, and accept that both of these phases of physics are incommensurable with one another, then this causes physicists some very serious problems indeed. Why should we consider the LEP-ring at CERN, DESY-ring in Hamburg, SLAC in the US, or the proposed LHC at CERN, to be commensurable with one another? Or, for that matter, the DELPHI, OPAL, L3, or ALEPH detectors in the LEP ring? These are different machines. Why stop there? Why should any two different analyses of data from DELPHI be commensurable? It seems to me that if we define incommensurability on the basis that no two stable performances are the same then no scientific work could be commensurable with any other. Each and every machine performance would be incommensurable with any other machine performance. If we follow this line then of argument then, eventually, we reach a point when we would have to conclude that every cultural element is incommensurable with every other and stable interactions are impossible (or an illusion). At that point

[15] These are not obligatory; histograms, graphs, and scatter-point plots are also common technographics.

"science", "culture", "element", and "practice", become meaningless atoms and Pickering's analysis collapses into the Mangle. We can avoid this by accepting that interactive stabilisations, made associations, can remain stable, but with no guarantee that they will do so in the future, and as such can be shared between different projects as techniques and machines. It does not make sense to consider a scientific practice part of a scientific culture if it has a unique set of cultural elements at its disposal. It would be disconnected. However, this does not mean that all scientific practices need to share an identical set of cultural elements and form a unified scientific culture. Instead, scientific practices share some elements, but not all, with other scientific practices, e.g. an archaeological project and a biological project could both use electron microscopes but have not much else in common. Instead of considering scientific projects as incommensurable islands, I consider them as chains of overlapping techniques, models, and machines. Each of these chains is a stratum and distinct strata are incommensurable with one another. Technological objects on the same strata are transfactual when they are used in different projects on the same strata, providing that the are repeatable, and are commensurable. Some particular scientific projects might not share any technological objects with other specific scientific projects, and they would be incommensurable. They must share at least one technological object with at least one other particular scientific project to be considered part of a scientific culture. For example, all experimental physics projects use machines and mathematical projection as their methodology. It is through the overlapping machine components, models, mathematical techniques, etc., that distinct experiments can be said to all participate in the same unitary discipline called "physics". Not all experiments need to share all the elements of every experiment. All that is required is that each experiment shares at least one element with another experiment in such a way that a connecting chain of shared elements can be stretched across all experiments. Thus the ontology of physics is circumscribed by overlapping strata of distinct machine-families that are unified by the methodology of the projected template and mechanical realism. If projects share stable elements then scientists can transfer between projects and build up a set of stable elements, a standing-reserve, which can be used as possible accommodations in future projects. In other words, scientists can built a stable set of experiences of making stable associations and use these as possible accommodations in other projects. Although this does not guarantee success it does mean that scientists can develop experiences, skills, tactics, strategies, and techniques, which can guide them in making selections of possible accommodations and, perhaps, improve their expectations of their chances of success. Technically rational choices can be made against the paradigmatic background of clusters and constellations of the standing-reserve of elements. By allowing scientific practices to share stable cultural elements, and scientists to learn from the experience of making them, it is possible that scientists can acquire a cultural stock of elements, which enables them to choose particular accommodations as possible solutions to particular problems. It is conceivable that scientists might even be able to acquire some degree of general knowledge of how to make machines. *Techne* lies on the horizon. It is because Pickering did not allow this possibility in his analysis that the choice of particular accommodations that particular scientists made to deal with particular problems is inexplicable to him except as *ad hoc* tinkering.

How do physicists un-mangle "the Mangle"? For Pickering this was inconceivable because he did not allow physicists to place "the Mangle" in the context of their pre-existing technologies and experiences; in his analysis, technologies and experiences were themselves only cultural elements fed into "the Mangle" for further mangling. He claimed that "...Morpurgo found that the charges on iron cylinders seemed to drift overtime – from zero to e/10, for example. *Tinkering once more in material practice, Morpurgo found a new way to frame material agency*, discovering that he could achieve stable measurements, again of zero charge, if he spun the cylinders."(p.59)[16] By treating this new technical practice of "spinning the cylinders" as "a new way to frame material agency" Pickering ignored the extent that "measurements of charge" are socio-technical evaluations which are situated in a theoretical and experimental context. What led Morpurgo to consider "that the charges of iron cylinders seemed to drift over time" to be a problem? And, what led Morpurgo to consider spinning the cylinders as a possible solution? Pickering, by not allowing "the Mangle" to be placed in a technological context, answered the first question by appealing to "resistances of material agency", and could not answer the second question at all. Although he did account for why Morpurgo had to make an accommodation he cannot account for why Morpurgo chose the accommodation he did except by explaining it away as "tinkering". Why didn't Morpurgo try slaughtering a chicken and dripping its blood over the apparatus? It might have worked! I would suggest that the reason why "spinning cylinders" appeared to be a possible solution, and "ritual sacrifice" did not, was because the legitimate choices available to Morpurgo were constrained by the paradigmatic technical background and by his current experiences. They were challenged, destined, and enframed. The drift, as a resistance, was a product of Morpurgo's expectations of what a good measurement would have been in that situation. The spinning, as a possible solution, an accommodation, was more a product of Morpurgo's technical experiences, and theoretical interpretations, of charge distributions and the properties of iron, than it was mere tinkering. I am not suggesting that Morpurgo knew what he was doing. Nor that his past experiences guaranteed that his solution would be successful. My point is that Pickering's isolation of this tactic as "material practice" was one which arose after a reconstruction of the mangled complex of expectations, perceptions, and evaluations, and is only possible if we take Morpurgo's work out of the wider context of experimental particle physics in which it is situated. Pickering claimed that Morpurgo developed an interpretive account as a consequence of his tinkering. I want to argue the reverse of this; Morpurgo only tinkered in this way because he had an interpretive account of why there would be charge drift on the iron cylinders and what he could possibly do about it. I am not suggesting that mere tinkering does not occur in experimental physics, not for an instant, but I do not agree that it is all mere tinkering, and I think that Pickering was suggesting that it is.[17]

If scientific practice is mere tinkering then is there any place for discipline? Is scientific practice all free-play? Pickering, paradoxically, emphasised the importance of discipline, which he termed "disciplinary agency" in the construction of conceptualisations and interpretive accounts. What

[16] My emphasis.

[17] Gooding argued (1990, p.141 and p.270) that materialism is an extreme which can be avoided by emphasising the connection between knowledge and the world through thought and action's interdependence. This is the point that I wish to make providing we emphasise that the connection is between *possible* knowledge and *the rest of* the world.

did Pickering mean? His concept of "disciplinary agency" was that of the sedimented, socially sustained routines of human agency which accompany conceptual structures as well as machines. He did not allow any notion of constraint, or demands, to be placed on human disciplinary agency by machines, or material agency for that matter, but instead had human disciplinary agency modified, as accommodations, as a response to resistances. For Pickering, disciplined agency occurs entirely within the human realm. Pickering contained discipline in the human realm because "the open-ended dance of agency that is scientific practice becomes effectively frozen at moments of interactive stabilization into a relatively fixed cultural *choreography*, encompassing, on the one side, captures and framing of material agency, and, on the other, regularised, routinised, standardised, disciplined human practices." (p.102) Given Pickering's thesis of productive "temporal emergence" of mangling, then, how could he incorporate fixity, regularity, stability, and discipline, into his thesis? He had to locate this stability into the human realm otherwise it would represent fixity in the emergent contours of material agency and we would be able to acquire some knowledge about how machines work in such as way so to enable us to build them. So how does this frozen choreography occur? It is because he rejected the notion of constraint, and did not discuss demands, that disciplinary agency could only be located into the human realm. If he were to allow constraints and demands of machines upon human agency then he would have been able to conceive of disciplinary agency in terms of sedimented human-machine relations in which discipline did not occur only in the human realm but as a consequence of constructing challenges and practices in terms that can be re-produced.

Pickering analysed disciplinary agency as occurring within the human realm in terms of passivity. He described this as *transcription*: the human agent is forced to copy the practices associated with the old model. However, by construing discipline as passive, Pickering misunderstood two things. Firstly, transcription is simultaneously, ambiguously, passive and active. Secondly, discipline involves more than copying. For example, writing 2+3=5 is not an example of discipline; it is an example of mimicry. Pickering treated discipline if it were something fixed and static which replaces human activity and intentionality. However, if we view disciplinary agency as an organised practice, which is productive and agential, then, especially in terms of Pickering's "open-endedness of cultural extension" thesis, it is inconsistent to treat that discipline as if it were complete. I can say that I understand how to do algebra, but does this mean that I can passively solve any and every algebraic problem merely by transcribing the disciplined agency of doing algebra? I would say not. Disciplined transcription requires interpretation as to whether or not it has been done correctly. Recollection of what has been done before is not sufficient to guarantee "perfect" transcription. This is the case with playing music, ballet, yoga, martial arts, gymnastics, and mathematics. Disciplined practice requires directed, continually interpretive, improvement and innovation of the practice towards perfection. The content of how to transcribe is underdetermined until every conceivable transcription has been done in the best way possible. In this sense there is constant ambiguity between this and what Pickering termed as *filling*. We can never be certain that we have "followed the rules" correctly and are always forced to take an interpretive stance. Pickering claimed that transcription is "a sequence of passive, forced moves... *that follow from what is already established* concerning the old model."(p.129) How could we know whether we have done this? In terms of Pickering's analysis, this must be "temporally emergent" in the real-time of practice. We could not know in advance whether we had correctly transcribed or not. By claiming that there are two distinct and identifiable phases of scientific work, actively constructing the apparatus and then passively observing the results, Pickering has built the human-material distinction into his analysis. This obscures the way that experimenters, like Morpurgo, *simultaneously* actively and passively perform experiments. The active choices that Morpurgo made in the construction of his apparatus were simultaneously passive responses to what, according to his current expectations and the paradigmatic technical background, was the best thing to choose. The passive observations that Morpurgo made, after switching the apparatus on, were simultaneously active as he attempted to make sense of what he was seeing, interpreting, in terms of his current model. Making observations involves simultaneously passively/actively interpreting what is happening during the experiment as the experimenter both orders the observations in terms of the structures of her/his current expectations, and orders her/his expectations in terms of her/his current observations. This is apparent when Morpurgo observed *an anomaly*. He was simultaneously confronted with this observation as an anomaly *in terms of his current expectations* whilst attempting to make sense of it, integrate it, *in terms of what he already knew*. When he could not, he had to adopt an alternative tactic, which Pickering characterises as conceptual. This involved modifying the formula for calculating charges on the grains by adding an additional term to the equation. However, contrary to Pickering, this tactic was both passive and active because it was an active modification of the formula that was passively part of the way that physicists have been taught to do physics. There was nothing radical or unusual in Morpurgo's practice here because he was choosing a possible solution from a considerable arsenal of tactics at his disposal (acquired throughout his education and experiences); this is how physics is done. This mathematical modification was made in relation to what Morpurgo could *measure* using his apparatus, how he could expect to *interpret* that modification as a physical mechanism, and simultaneously what he could expect to *demonstrate* using an electromagnetic-mechanical apparatus. The configuration and functionality of the apparatus was constructed *within* the interpretations and tolerances of Morpurgo's current knowledge, *and,* his expectations of the functional and demonstrative potentials of his models. At this stage of his work Morpurgo's models, interpretations, and apparatus' functionality, were all mangled together. At this stage his work was far from complete. His task was to disentangle these elements in order to be able to differentiate between theoretical expectations and actual observations. It is only by differentiating material agency and human agency that Morpurgo could establish his experiment as a demonstration of the existence or inexistence of free-quarks. It is in this sense that experimental practice is a "unmangling" of "the mangled".

<u>Machine Agency:</u>

In Pickering's analysis the emergence of material agency was dependent on two assumptions: (a) that intentionality occurs in the human realm, (b) that physicists adopt a passive role. Are these assumptions justifiable? How can physicists know when they have been suitably passive or not? In my view, a physicist has to *interpret* her/his posture, in relation to other physicists, in order to answer this question. The judgement on whether or not this has been correctly done is one of interpretation and consequently the physicist is always in an active role even when evaluating her/his own passivity. The physicist has to attempt to control her/his control in order to distance her/himself from the performativity of the experiment. S/he has to answer questions like: "What is the apparatus doing?" and, "Why is it doing it?" before s/he can be confident that her/his interpretation is that of the apparatus "doing its own thing". Hence the desirability of *techne*. Once we allow this activity in interpretation then we have to concede that judgement is involved in the decision of whether or not material agency has been captured. This inability to extract human agency from material agency on the basis of passivity makes Pickering's assumption (b) very problematical because there is no stage during the dialectical process of accommodation and resistance that we could identify material agency *qua* material agency without arbitrarily doing so. Pickering had resistances primarily localised in machine performativity due to material agency, rather than due to human agency, although not consistently throughout the analysis.[18] As he puts it (p.39), "I use "resistance" in just this sense of practical obstacle, and I do not mean it to refer to whatever account scientists might offer of the source of such obstacles." However, I do not think that Pickering could separate the two, without arbitrarily doing so, because the extent to which something *is* "a practical obstacle" will depend, in part, on scientists accounts of not only what constitutes "a practical obstacle" but also her/his account of the source of that obstacle. Physicists' accommodations to *interpreted sources of resistance* will vary depending on what they take those resistances to be. Some interpretations may lead them to cease the project completely as being far too expensive or highly unlikely of being successful. Morpurgo serves as a good example here. He eventually stopped trying to find free-quarks, after fifteen years of making accommodation after accommodation, to resistance after resistance, including changing his theoretical models, redesigning and rebuilding his apparatus, enlarging the size of his group, etc. What was the resistance that finally compelled him to stop? He finally interpreted the machine performativity to mean that either free-quarks did not exist or that he would not be able to find them with this type of machine. It seems that the final resistance that ended the project was Morpurgo's *own account* of why the experiment had not shown any free-quarks. Such accounts of the nature and source of a resistance have a vital role in the perception, selection, and evaluation, of the practicality of any possible accommodation or intention.

Was Pickering's assumption that intentionality is located in the human realm justified? Pickering had to locate intentionality in the human realm because he had rejected that *constraint* and *demand* play any role in the construction of intentions. He rejected the former as a humanist concept and did not discuss the latter at all. In Pickering's analysis of Glaser's project of building a bubble-chamber, Glaser's intentions were only transformed as accommodations to machine performativity, and material agency, in terms of what Glaser *did next* (pp.37-63). Pickering claimed that, although the actual form the bubble-chamber eventually took was "dialectically transformed" throughout the

[18] For example, p.42 emphasis mine, "Here another resistance was apparent. *Since cosmic rays arrive at the surface of the earth erratically, there was little chance of detecting interesting cosmic ray events by expanding a bubble-chamber at random intervals: the odds were high that nothing would be happening at the instant chosen.*" Here we see a physicist's account acting as a resistance against "expanding the bubble chamber at random intervals" as a possible accommodation.

process of building it, the original project of "building a bubble-chamber" had its origin in the human realm. It was only in terms of how Glaser modelled a working bubble-chamber, and went about trying to build one, that we find any transformation of intentional structures. So, according to Pickering, although Glaser's intentional structures of goals and plans were "emergently mangled", through "a real-time dialectic of accommodations and resistances" between "Glaser's practices" and "machinic captures of material agency", the original intention of "building a bubble-chamber" had its locus in Glaser when "he set himself a new goal". To what extent did this new goal have its origin in Glaser?

In my view, if Pickering allowed constraint and demands to play a role in his analysis then he would not have been able to locate intentionality only in the human realm. Machines and tools form part of any set of cultural resources (or cultural elements, as Pickering puts it) and, combined with techniques, and experiences of when, and how to use them, provide a set of technologies. These technologies are as much a part of the "diverse set of cultural elements", that Pickering feeds into the Mangle, as are concepts, representations, interpretations, and materials. As I have already argued, particular technologies, as means to ends, are connected to the teleological positing that they promise to satisfy. These positings are also a cultural resource. These are the perceived potentials, possibilities, and challenges that are associated with any technology which arise out of an innovative culture destined towards ever increasing transformative powers. There are expectations and notions of appropriate usage which facilitate the selections and choices made when deciding which technology should or should not be used. The existence of technologies provides possible goals and projects that would be inconceivable, or considered unachievable, without them. When a new technology becomes an available cultural resource it brings with it a whole range of potentially achievable new projects and goals. Without access to these new technologies, human choices are constrained by what are perceived to be achievable (or technically rational) using the already existent technologies. In the context of experimental physics the physicist is constrained in her/his choice of technology according to the consensus of other physicists regarding what can or can not be demonstrated by using particular techniques. A physicist also has a technological *demand* placed upon him/her to use only theories, interpretations, and intentions, which contain *measurable* elements and consequently the choice of theory, interpretation, and intention, is constrained by the limitations of the available measuring technologies. The physicist is enframed by the template of methodology. Furthermore, once a technology has become established, and particular positing have become routinely accomplished using those technologies, then the cultural sedimentation of those positing is simultaneously a cultural sedimentation of those technologies. If culture can be said to be a stable form of life then it is also a stable set of technologies. In this sense there are both constraints and demands placed on intentionality by technologies when human agents elect to only choose goals for which they have the technologies by which they can achieve them. There is also a consensual demand placed on human agents to choose the technologies that have become established as the means to achieve culturally acceptable purposes and goals. Furthermore, the imperative to innovate is central to experimental physics; it challenges human agents to innovate solutions to technologically produced problems. Thus Glaser was challenged to invent the bubble chamber in accordance with the positing, potentials, demands, and constraints of the technical background of cultural resources in which he was situated. Glaser was destined as soon as he took up the challenge. If Pickering were consistent in his "posthuman" thesis then he would have treated intentions as cultural elements that are not localised in the human realm but as products of "the Mangle". Using the Glaser example, the intention to "build a bubble-chamber" was a possibility, conditional on the existence of various technologies and goals, which became a potential as they found their way into the field of particle physics. As an intention, it was available to anyone who had access to all the cultural elements which made it possible, and, "it just happened" to be Glaser who picked it up and tried to make it work. Such a goal could only exist as a result of the promises and limitations of the technological culture in which Glaser was situated. There is no reason to presuppose that it began with him. As a physicist there is a demand on Glaser to actually do some physics. What "doing physics" involves will depend upon the culture in which he is situated, and due to this dependency upon culture, Glaser found himself in a culture where only specific potentially achievable projects and goals were perceivable. I accept that he could have chosen to attempt something for which there were not perceivable cultural resources, like building a time-machine, but the perception would have been that failure was likely and Glaser would have taken a considerable personal career risk by electing to take up that challenge. Building a time machine was not a culturally available goal or project, in the context of the technical background in which Glaser was situated, but building a bubble chamber was. As Pickering argued, perceptions of success or failure are themselves emergent as a result of the Mangle. It was inconsistent of him not to extend this thesis to perceptions of *likelihood* of success or failure. Intentions must be emergent in the same way as any other cultural element and cannot be localised in the human realm. Pickering has taken the intention of "building a bubble-chamber" out of the context of a technological history which preceded Glaser's work and has neglected the rôle that the available technologies of that period had in offering up substantial directions of exploration and potential success. Human choices, decisions, and intentions are shaped by the technologies that are culturally available. The existence of particular technologies is a pre-requisite for particular choices, decisions, and intentions. Glaser could not have intended to "build a bubble-chamber" if he were born into Galileo's culture; it would have not been a possible choice. Nor could Morpurgo have intended to search for free-quarks by sacrificing a white ox at Stonehenge during the summer solstice; it would not have been an appropriate technology within his culture. Particular research projects require particular technologies and particular technologies suggest future research projects. Research projects, choices, decisions and intentions, are shaped by the technologies that are available.

However, I am not attempting to attribute intentionality to machines. Even in the fields of AI and robotics it would be contentious to claim that there are machines that have intentions. When I say that machines *have agency* then I do not mean to imply that they voluntarily do so. So in what sense can machines be said to be agents that cause specific intentions? Technology is not merely comprised of machines or tools; a machine or tool is not a technology. A technology is comprised of machines, tools, *expectations of tasks that are achievable with that technology, the know-how to use those tools and machines*, and bodily organisation. Without know how and expectations we could not know when, or how, to use tools and machines, and we would not expect them to work in particular contexts and perform specific productive acts; tools and machines are useless without technique and expectations. Both humans and machines transform each other. The situation is one of feedback. It is in the context of feedback that machines can be said to have agency. Technology is constituted through interaction of human agency and machine agency. My point is that Pickering treats intentionality in a way that is inconsistent with his thesis. In terms of the Mangle, intentions should occur as interactive stabilisation of human agency and machine agency, as cultural elements, and should not be localised only in the human realm.

As I have argued above, Pickering's assumptions that human agents adopt a passive role, and that intentionality is located in the human realm, are both problematical and are the source of inconsistencies throughout his analysis. His argument did not support the notion of "material agency" because it is an *ad hoc* construct, designed only to account for resistances to human intentions, that is only apparent when periods of human passivity are assumed to happen. Machine agency is the experiential ground of such resistances and accommodations that arise through experimental uses of machines. It is an assumption to consider these machines as intermediaries. Material agency is a metaphorical substitution, which occurs when machines are made transparent *as mere means* and are treated as intermediaries. He required material agency because he has no space in his analysis for machine agency except as the machine-like intentionality of human agency, in disciplined relation with material agency, and as an intermediary for the accommodations and resistances of the interaction between human and material agency. It seems to me that if Pickering was to offer us an analysis that was based upon cybernetics, which is something that he alludes to but does not systematically work through his own analysis, then he could not consistently contain intentionality in "the human realm". If we restrict our analysis of experimental physics to its performances, as Pickering implored us to do, then we have no experience as machines as intermediaries except in terms of what is said about them. What we have are machines and our interpretation of their performativity in terms of mechanisms. It seems to me that we can only describe these machines as intermediaries between human agency and material agency *only because such a way of discourse is a product of removing the machines from the account and replacing them with Nature* (or material agency in Pickering's case). It is a part of our cultural tendency to accept that the Archimedean, Baconian, and Galilean faith, that Nature can be disclosed by mechanical devices and mathematical inscriptions, is justified. It is this cultural tendency that I have referred to as mechanical realism. The belief that this faith is justified is presumptive. Whether or not experimentation can provide us with such knowledge is something that we are not in a position to answer one way or the other without arbitrarily doing so. It is because Pickering has an inbuilt asymmetry in his account, that human agency attempts to "capture" material agency, starting from human intention and passively responding to material agency, intentionality is situated on the human side of the dialectic. He has made the traditional assumption that machines are nothing more than a means, a transparent intermediary, for the capturing of material agency. It is this assumption, that machine performativity and material agency are intimately connectable but not the same thing, that has led him to make the essential concession to this tradition. If we examine machines *qua* agents rather than intermediaries or mere machines then we can develop a rather different description of experimental physics than Pickering does in terms of human-machine interactions and relationships.

Material agency is a metaphorical product of particular modes of human-machine relations, directed to the production of a knowledge of general principles of mechanism and functions of mathematically abstracted mechanised agencies, in order to metaphorically make the world intelligible to human beings in terms of mechanisms and functions. I agree with Pickering that neither the social constructivist nor realist accounts of physics, taken on their own, provide us with a satisfactory account of experimental physics. The challenge is to take both accounts into account, without taking a partisan position on either, with the aim of producing an intelligible account of experimental physics. Although Pickering is partially successful, by showing the deficiencies in both the social constructivist and realist accounts of physics, by holding that there a nonhuman agency which is emergently produced through human agency working on machines, he has ultimately assumed that machines are intermediaries between human and material agencies. If we do not accept this assumption, that machines are intermediaries, then what does this imply about "material agency"? "Material agency" is a fictional product of particular human-machine relations and is not a pole (or terminus). It is a product of interpretations of machine agency. It is only through particular conceptual structures, socio-technically constructed and inherited, on the basis of metaphysical presuppositions, that notions such as "material agency" can be emergent. The "material" is a product of particular modes of agency rather than a mode of agency itself. It requires further rhetorical and conceptual work to transform it into a mode of agency (as Pickering has done). This work metaphorically transposes the machine into an intermediary. The nonhuman agency in question is the agency of the machine. The nonhuman agency of a machine does all the work that Pickering wants material agency to do. Human agents and machine agents are distinct but inseparable from one another in the context of experimentation and knowledge production. Machines are products and embodiments of intentions, expectations, beliefs, choices, and values, and as such are constructs. Conversely, human beings are machine users, and as such, new machines, when used, generate (not just transform) new intentions, expectations, beliefs, choices, and values, through the powers, constraints, challenges, and demands, that they make upon us. Human and machine agencies shape each other. Human agency and machine agencies are products of each other.

Furthermore, the materials used in scientific work are themselves integrated into machine agency in order to determine their properties. In the construction of an experiment, each material is a component that is integrated into the apparatus on the basis of what that component, that material, *does* to the other components, the other materials, to which it is connected and acts upon. Each component is organised in terms of its productive agency, as an input-output function, within the structure of the machine in which it is a component. These machines, in turn, can be analysed in terms of the larger organisational structures in which they are integrated as components. The material agents are *other machines* that, when connected together, form "emergent brute resistances" in accordance with the degree of incoherence that occurs as a result of these connected machines having divergent centres of transformative power. This resistance occurs when transformative powers interfere with one another. Coherence is achieved, resistance disappears, when these divergent centres of organised agencies are brought together into a single centre of organised agency. At that point a working machine has been made which operates as a stable unitary agent. For example, in Glaser's work, by attempting to connect diverse components together with the aim of constructing a unified machine, the bubble chamber, each of those components began as its own centre of agency (as a result of previous unification within the work of others) and the problem Glaser faced was bringing these diverse agents together into a coherent whole with a single centre of agency. The resistances arose through the problem of achieving stable co-operation of functionality as each component was connected. When components competed, each had divergent functionality, and the outcome was a dysfunctional configuration of components. This divergent functionality is a consequence of components being brought together to perform functions, for which they were not designed, developed, and stabilised. Each component, as a centre of functional power, unless brought together with all the other components, as an integrated whole during the process of innovation, undermines and interferes with the functional power of the components it is connected with. This incoherence cannot be identified with an "emergent material agency" precisely because it arises due to the fragmentation and disharmony of agencies rather than from a unitary source. It is a product of heterogeneous agencies. Glaser had the additional problem of having to integrate his bubble chamber into the wider context of particle physics. This involved connecting his machine, as a componential complex, as a component in the larger technology of particle detection. Achieving stability involved not only integrating all the componential agencies of the parts of his machine but also integrating his machine, as a component, into particle physics. His work required integration on both a micro and macro level before he made a working bubble chamber. This interaction between micro and macro level organisations of agencies involves not only integrating electrical components, glass tubes, and strange gases, but also involves integrating techniques, interpretations, conceptualisations, political institutions, economic factors, social organisations, beliefs, values, and expectations, together into a stable centre of functional power. It is only by doing this can new machines, like bubble chambers, be made to work and become part of scientific culture. As such, resistances are the result of sociological, psychological, political, economic, and technical incoherence. By treating "the source" of such resistances as the interaction of human agency and material agency, Pickering has substituted "material agency" for the wider context of the integration of innovations into pre-existing technological and social orders.

After all, what is a machine? It is not merely a particular configuration of matter (metals, plastics, glasses, gases, etc.) but it is a particular configuration of functions. Even the so-called basic "stuffs" from which this machine is built are functional components with their own histories of stabilisation. Take iron for example, this "stuff" is itself identified in terms of its functions of hardness, durability, tensile strength, availability, cheapness, etc., and all these functions have taken considerable work to organise into a coherent unity. Iron does not "come out of the ground"; iron ore does. Iron ore is dug up; iron is made. Machines are anything that is made to reproduce a performance, function, or functions, through integrating diverse agencies into a coherent functional unity, and, as such, may be mechanical, mathematical, computational, social, political, military, biological, medical, scientific, analytical, or sexual. Functionality does not come "of itself"; it requires work (organised power) to set-upon otherwise heterogeneous objects, gather them together, order them, and integrate them into a stable, coherent, and unitary function, from an embodied technological background. It takes effort, resources, and power. Functionality is made upon *the anvil of practice*.

Despite Pickering's insistence that "the Mangle" *decentres* intentionality from the human subject, his characterisation of "the Mangle" as a *struggle* between human agency (described as intentional structure and its social contours) and material agency (described as an emergent brute resistance with its material contours) is one which maintains the mental-material distinction in the form of an intention-resistance distinction. Without this distinction there can be no notion of a struggle. This notion of a struggle is implicit to Pickering's analysis and, consequently, it is readily open to interpretation as a reconfiguration of Marx's concepts of "dialectical materialism", "history", and "labour", in order to apply them to modern experimental physics. Pickering wrote "resistance emerges at the intersection of human and material agency, and as the present argument suggests, serves to transform the former in one and the same process as it delineates the latter. Just as the mangle, then, pulls material agency onto the terrain of human agency, so it materially structures the goals of human agency. Just as the evolution of material agency lacks its own pure dynamics, so too does the evolution of human intentions."(p.58) Here we can see the difficulty that the inherent mental-material structure in his analysis was causing him because his analysis required that intentionality is contained within human agency but is structured by material agency to the extent that there is neither a pure human dynamics nor a pure material dynamics. And yet, he introduced the notion of resistances from material agency in order to account for the way that human intentions are not immediately successful, but has ended up concluding that there is neither any pure material agency nor any pure human agency. If that is the case then intentionality cannot only be described in terms of human agency and therefore there is no need for the introduction of the mysterious material agency to account for resistances. Resistances can be accounted for by examining the structure of intentionality, in terms of means-ends relations, in the dynamic interaction between heterogeneous agents, which may cohere or incohere with each other, and, consequently, dynamically produce stable or unstable intentional structures. In such an analysis a stable intention occurs when there is the technique available as standing-reserve to achieve the challenge in question and an unstable intention is one in which either the technique or the challenge is indeterminate or unavailable. If all we can analyse is the "interaction" in terms of properties and characteristics, then we are limited, in experimental physics, to analysing machine performativity of particular machines, in terms of the relations, structures, organisations, orders, and agencies, from which those particular machines are constructed, and the ways that those machines relate to knowledge as an ideal. In other words, if we are to genuinely attempt a "posthuman" analysis of experimental physics then we are directed towards a deconstruction and analysis of machine agency the contexts within which machine agency is situated and constructed. In Pickering's terms, if there is no pure human realm and no pure material realm then both must be internally related; that is to say that they only exist in relation to one another as aspects of the Mangle. The Mangle is the interaction between the two aspects of itself. What sense can we make of an intersection, or boundary, of two things that only exist on that boundary? What sense do the concepts of interaction, intersection, and boundary make here? Surely there can be no such identifiable boundary, intersection, or interaction, and the notions of "resistance" and "accommodation", except that of machine agency. If Pickering wished to fully develop a "posthuman" conception of scientific practice, in a consistent fashion, then, in his terms, human agency, material agency, machine performances, history, temporality, practices, concepts, models, representations, intentionality, resistance, and accommodation must be products of machine agency. In a posthumanist analysis, machine agency must be *both* "posthumanist" and "postmaterialist". The scientific processes of machine agency could only be analysed as processes by which its own constituents were its own products; where its own possibilities, potentials, and actualities, were its own object. In short, the mechanical realist ontology is both its own product and resource, extended through its own machine agency, in order to produce itself, *and nothing else*. Machine agency can only be analysed in terms of the elements that were produced by it and *re-iteratively* fed-back into it. And so on.

Pickering offers us an interesting metaphor. This metaphor functions to make experimentation an unintelligible, mysterious, magical, and, as C.S.Peirce put it, "an occult power". By taking this metaphor literally Pickering has made experimental science as opaque and mysterious as "the dance of Shiva". However, as I have argued throughout this thesis, we can analyse the role that techneic ideals, underwritten by mechanical realist metaphysics, has had in the production of "the laws of Nature" and "natural mechanisms", without either accepting the validity of that metaphysics, or making a miracle of the "progress of physics", whilst examining how knowledge, as *techne*, can be used to guide the productive processes of machine agency, as an ideal. Perhaps, we should invoke the metaphor of Hephaestus, the Greek god of fire and making, to stand by Shiva, the creator and destroyer, when discussing possible divine patrons for experimental physics. After all, in the terms of my argument, "the laws of Nature", the transdicted *technai* of experimentation, are products of the "anvil of practice" that are given up to the eternal and universal "realm of the gods".

Does Anything Enable Us To Build Machines?

Pickering, by answering negatively, has pre-empted a judgement on the validity of mechanical realist metaphysics and arbitrarily asserted a response. In many ways this is the central but unasked question of experimental physics as a whole. Or, to put it another way, the construction of experimental physics is itself a performative attempt to answer this question by building machines and attempting to present causal accounts of how they work. Experimental physics, as a mode of *Ge-stell* challenged to achieve its own *techne*, is an ongoing process of producing causal accounts of the technological innovation of transformative powers as technological objects for further innovation. The challenge for experimental physics is to explore every conceivable possibility of its own destining. It can not end until it has undertaken every challenge that it sets upon itself. In other words, the task of experimental physics is to design, build, operate, innovate, and perform every possible experiment upon every possible machine-kind. However, even if we imagine this to be a finite task for which completion is a possibility, this still raises the question of whether experimental physics will ultimately provide the answer it was set up to provide. Whilst the object of experimental physics remains the mechanisms disclosed through machine agency it will not answer this question. Why? Physics is challenged to build novel machines to explore the laws and mechanisms in operation upon the interface of machine performativity. Thus it is destined towards the question of what enables machines to be built *as if* the answer was itself something mechanical. However, what physics can not address is the being that builds machines in order to understand how they work. It can not address the "us" of the question. This is a question of the *poiesis* that is emergent through the interactive relationships between human agency and machine agency. It is a question of the psychophysical processes of human-machine productivity. The question of what enables us to build machines is a question of the origins of the possibilities and conditions of the processes of labour themselves. This is a questioning of our Being and the Being of the world. The mystery at the heart of the labour process is the mystery at the heart of our being-in-the-world. Why is the world like this? Why are we able to act in the world in the ways that we do? Why are we like this? This questioning has been with us since the ancients and remains answered. The presupposition of natural laws does not answer this questioning. It only conceals it. For even if there were natural laws we still would not know why there are natural laws at all, or why they have the form that they do. Whence the resistance? Technological objects combine with one another. The greater the number of technological objects the more combinations of technological objects are possible. Technological objects exercise their transformative power in interaction with other technological objects. This transformative power is the product of an ensemble of technological objects in which each technological object is itself an ensemble of other technological objects. Errors are always possible because it is impossible to foresee all of the consequences of implementing any technological object. Experimentalists do not know what they have done. The technological object can only be determined in relation to the ensemble in which it has been integrated as a component. The innovation and integration of any novel technological object in an ensemble of other technological objects transforms the productive equilibrium of that ensemble. It disturbs the context by changing the context. This is the nature of innovation. Ellul (1964, pp.111-2) provide a good example of this in his discussion of weaving. The eighteenth century invention of the spinning jenny by James Hargreaves allowed the production of more yarn than could be used by weavers. Cartwright invented his famous loom in response to this disequilibrium. The problem facing us with the question of the origin of resistances is how do we locate the source of resistance. Labour processes are complex and are situated within contexts of heterogeneity. It is the experimenters' efforts to determine the transformative power of any object that permits experimental physics to participate in discovery. This discovery is the discovery of modes of agency and not simply the discovery of truth. If truth is implicated then it is as *aletheia* rather than *veritas*. It is disclosed as reality rather than corresponding to reality. Agency can not be readily divorced (or abstracted) from its context of occurrence and, consequently, the claim that experimentation discloses a pre-scientific truth (or reality) requires a reification that is itself the product of the mechanical realist precepts. This means that any technological object only achieves the status of a natural object in virtue of the additional work of the metaphysical projection of the human participants. This participation is itself a mode of agency in which the precepts of mechanical realism are themselves characterisable as functioning technological objects. The transformative powers of any technological object can not be evaluated *independently* from the environment in which that technological object interacts. The transformative powers, as causal powers, are established in relation to the change that occurs as a result of that technological object and its environment. What is a mechanism? It is an index for a reproducible change. What is a machine? A machine is an interconnected ensemble of mechanisms that when acted upon reproduces functionality. This production is the agency of the machine. It is a centre of transformative power. Each component mechanism reproduces a centre of transformative power. If these component centres are integrated into the network of the machine coherently then the machine works. It produces the desired actions when acted upon. It works. Coherence occurs when the centres of power of the components are converged upon a total action. Incoherence occurs when there is more than one total action. The centres of power are divergent and the machine does not produce the desired action when acted upon. It does not work properly, or at all, because the centres of power interfere with each other, or cancel each other out. The malfunction of a machine is the result of incoherence between actions. It is a state of disorder and diversity leading to conflict and competition between centres of functional power. The construction of a machine involves bringing together, integrating, separate mechanisms. This involves integrating a diverse collection of centres of transformative power into a single centre of transformative power. It involves totalling them into a single total action. The construction of a machine is to make transformative powers coherently reproduce functionality. It is an ordering process aimed at making coherence to produce a single centre of functional power. Building a machine is a process of integration of diverse agencies into a single agency.

The selections and demands that occur in the development of new machines and practices cannot be localised on either side of a human-machine relation because both act upon each other. The process of construction is an interaction both; it orders action according to a template analogously taken from another machine. The cybernetic process of control-information feedback is the interaction between coherence and incoherence. Any machine is a particular framework of interactions, which itself interacts with the agencies of the environment in which it is contained. The boundary of the machine is ill defined. It is open. Machines are frameworks within larger frameworks. Making a machine work can be done in one of two ways: (1) Adding agents to the incomplete framework until coherency are achieved; (2) changing the incomplete framework to contain more agents until coherency is achieved. There is no depth to this process. It is merely a process of extension and integration. It is a process of *Ge-stell*. Pickering oversimplified building machines by analysing it in terms of two agencies: human agency and material agency. In my view, we cannot make building machines intelligible by analysing it in terms of dialectic between these two types of agencies. Building machines involves *integrating* a diverse set of agencies. Each agency is simultaneously social and technological in construction and as a consequence of this dual nature cannot be situated as originating in neither a human realm nor a material realm. It requires analytical agency in order to identify "a human realm" and "a material realm". If "the realms" are interpenetrating, as Pickering suggested, then the selection of origin of types of interaction, namely intention and resistance, is an arbitrary selection. Agency is always a culturally situated productive dynamic orientated to effecting change and making things happen. Agencies, in this sense, are centres of functional power, organisation, and ordering. These agencies can be of a psychological, logical, philosophical, economical, political, componential, mathematical, functional, textural, interpretational, conceptual, sociological, historical, dextural, procedural, technical, semiotic, moral, analytical, or engendered function. Whilst we remain at this level of analysis we can make "modernist" analyses of science which allow the construction of definite statements about, and deconstruction of, practices in terms of characteristic types of agent. However, if we deconstruct each of these agencies to analyse their components in terms of any, or all, of the other components, e.g. economic agencies in terms of gender, or gender agencies in terms of political agencies, then we move towards "postmodern" analyses of science which open up the construction of experiments, and their intergration within wider culture, to a potentially infinite multiplicity of interpretations. Although such analyses are always incomplete, selective, and ephemeral, they help us to unmangle "the mangle" and see how the various agents interact in the construction of experiments, techniques, and machines. Philosophers, historians, and sociologists have examined experiments in terms of their rhetorical, organisational, economic, or epistemological role, but it has only relatively recently that the question of how experiments are constructed has been raised. There is some literature on the exploration of experimental science in terms of material practices.[19] Experiments have also been analysed in terms of skills and social networks.[20] Following on this body of work, this thesis has taken practices as the starting point in the analysis of experimental physics. But what are practices? The above commentators discuss their role at length but largely leave the term undefined. The following definition is consistent with the above analyses. A practice is a repetition of a juxtaposition of agencies in order to gain reproducible transformative power. It involves performing an action repeatedly, or habitually, in order to gain transformative power. Practices involve a set, or collection, of repeated actions in the context of a project or programme of work. Practices are organised bodily movements and technological objects. In the context of experimental physics they are linked with the apparatus through the process of working upon it. Practices are mechanised actions when linked with a machine that transforms the undisciplined body and the experimental apparatus into a cybernetic organism. When the machine has become transparent the human body has become empowered by becoming more machine-like.

Throughout this thesis I have described the objects of scientific discourse as technological objects. These objects can be both intransitive and artificial. How can we make an intelligible account of such objects without assuming realism? This depends upon what we take such objects to be. If we take them to be the causes or mechanisms at work in an experimental apparatus, as Bhaskar does, then we can still provide an intelligible account of these objects without assuming realism. They are the points of linkage between machines in two respects. Firstly, scientific discourse utilises the general concepts of "cause" and "mechanism" during the process of determining which particular causes or mechanisms are actually in operation during particular experiments. A discursive space is created in scientific discourse prior to any commitment to particular mechanisms or causes. Even though scientific discourse is techneic there are stages in the construction of that discourse prior to any claim to techneic knowledge. There are pluralities of possible mechanisms that can be inscribed upon any technological process and, consequently, the process of inscription does not require any complete knowledge. Such knowledge is to be a product of this process rather than a condition. During the stages of inscription, particular mechanisms have not been permanently inscribed upon the apparatus and the "intransitive object" is the space for such future inscription. The design of the mechanism to be built is still on the drawing board as a challenge. Secondly, as any apparatus can be inscribed with alternative functives, and their associated transdicted mechanisms, when novel technographe are innovated and alternative interpretations of machine performativity are proposed, the "intransitive object" cannot be taken to be any particular technographe or interpretation either. These particulars are

[19] For example, Shapere (1982), Hacking (1983), Cartwright (1983), Ackerman (1985), Pickering (1984a, 1984b, 1995), Galison (1987), and Gooding (1990).

[20] Collins (1976), Latour & Woolgar (1979), Knorr-Cetina (1981), Pinch (1986), Galison (1987), Gooding (1990).

"transitive objects" whilst "the intransitive object" is the space created to be filled. It remains intransitive whilst particular machines are subjected to processes of inscription with technographic functives whilst the particular inscriptions used are transitive. As such, it remains independent from any particular objects that may have been produced by such processes but remains dependent upon the process itself for its existence. The "intransitive objects" of scientific investigation are independent of particular statements of scientific speculation but dependent upon the technological process of scientific investigation. Without the process of scientific investigation no such objects would exist. For example, early experiments upon photoelectric devices sought a mechanism through which the working of such devices could be explained and inscribed. It is this project which created a discursive space for such a mechanism which, subsequently, was filled with Einstein's formulation of "the photoelectric effect". Prior to filling this space it was the space itself that was the "intransitive object" and it remains available for de-inscription and re-inscription by any future formulations. Within the process of inscription, this discursive space is an intransitive technological object as a challenge, and not necessarily a natural one.

Once we have established an intransitive object, such as "the diffraction of light", through technological enframent, then we can have a plurality of ways of inscribing such an object. It is in this sense, that the technological object is independent of any particular form of inscription. It can be inscribed in terms of the technographe of classical wave geometry, the technographe of Newtonian ray geometry, or the technographe of Feynman's Quantum Electrodynamics. Provided that the same technological template is used to produce this technological object, "the diffraction of light", then these different technographe are commensurable. They can be compared by their utility in inscribing the technological object, their success at tracing its performativity (its predictive success), their extendibility throughout the machine-kind (optical machines), and their transportability to other machine-kinds (i.e. electronic machines). They are commensurable, as functives, in terms of bounded technical rational judgements regarding their instrumentality, aesthetics, and transportability. Functives transdicted into entities, such as "light waves" or "neutrino oscillations", cannot be said to have predictive success until they are transdicted back into functives and used, successfully, in the design, construction, operation, and interpretation, of the extensions of machine-kinds. This can be seen in the increasing acceptance of the "neutrino oscillation" transdiction. This has been made in response to the successful implementation of it as functive in an exoframe for the KAREL II machine. This feedback process is an essential feature of the development of novel experiments, the progress of physics, and the postulation of the existence of theoretical entities. The "acid tests" of any scientific theory is whether it (1) provides functives for the further development of machine-families and techniques; and, (2) whether it provides intelligible causal account of the phenomena in question. One of the prime difficulties for quantum theory, for instance, is that it satisfies condition (1) but does not satisfy condition (2). However, the success of quantum theory in satisfying (1) is sufficient for it to be continued as a part of mainstream physics until an alternative theory, which satisfies (1) and (2) for the same kinds of machines (and perhaps new ones), can be found. However, it does not follow from condition (1) and (2) that any such theory is (a) true of Nature or (b) the ultimate explanation. Neither technological utility nor explanative intelligibility are necessary or sufficient criteria for objective truth about Nature. It is logically possible that objective truths about Nature are both technologically useless and incomprehensible. My point is that useless and incomprehensible truths will never be a part of physics, and any truth that is part of physics has been disclosed by building a machine. But what of their transformative power? Hiroshima was not a shadow. Radios work more often than not, aeroplanes fly, and lasers can burn through metal. How can we argue against the scientific realist? In the next chapter I shall turn to the central question. What is the fire of Hephaestus? What empowers the creation of machines? What is the source of transformative power? Is it Nature?

CHAPTER SIX:
THE FIRE OF HEPHAESTUS:

"...truth consists in a conformity to something *independent of his thinking it to be so*, or of any man's opinion on that subject... the only reality there could be, would be conformity to the ultimate result of inquiry." C. S. Peirce. *Collected Papers*, 5.211

"The fact that an idea emanates from a particular class, or accords with their interests, of course proves nothing as to the idea's truth or falsity." Kautsky, 1902.

"The criterion for truth is the enhancement of the feeling of power." Friedrich Nietzsche (*The Will to Power*, Aph. 534)

Hyle and Resistance

The innovation of electricity, nuclear power, aeroplanes, plastics, etc., has changed the world. I do not doubt that the experimental sciences have brought new transformative powers into the world. What is the source of transformative power? Is it Nature? Is it a case of acting in accordance with Natural Law? What is the source of the reality disclosed by experimental physics? Can experimentalists understand the powers that they release into the world? Oersted, Biot, and Davy's experiments with a magnetic needle, a chemical battery, and a wire, provides a simple example of a case of bringing-forth a transformative power. The integration of a magnetic needle, a chemical battery, and a wire, is a machine put together to disclose a transformative power. Oersted reported in 1820 that a magnetic needle moved when placed near a wire that was connected to a battery. Oersted proposed, on the basis of this discovery, that an electric current causes magnetic effects. In his report, he provided us with instructions about how to perform this experiment and see this effect for ourselves:

"...The opposite ends of the galvanic battery were joined by a metallic wire, which... we shall call the *uniting conductor or the uniting wire*... Let the straight part of this wire be placed horizontally above the magnetic needle, properly suspended, and parallel to it... Things being in this state, the needle will be moved, and the end of it next the negative side of the battery will go westward..."[1]

Oersted provided us with a technique to produce this effect for ourselves. Try it. It is not as easy as is rumoured. Without fearing the risk of going native, I have tried to produce this effect for myself, and the needle does move, but it does not move in a clear and stable way. It is rather chaotic and it is difficult to witness the effect and keep the needle from touching the wire. It is this chaotic behaviour that Gooding

[1] Oested, H.C., 1820, "Experiments on the effect of a current of electricity on the magnetic needle", *Annals of Philosophy*, 16, pp. 259-276, p. 274. Quoted from Gooding (1990) pp. 30-1.

termed "the participation of nature" and Pickering termed "material agency". Both terms echo with Tartaglia's *potentia*, Moletti's *natural principles*, Bacon's *natural powers*, and Giovanni di Guevara's *natural motions*, in that they were all referent to the response to human intervention (or *violent motions*). Gooding termed the way that the needle does not move according to human dictate as "the recalcitrance of nature"; Pickering termed it as "material resistance". Both terms echo with Tartaglia's *material hindrances*. Latour and Woolgar (1979, p.243 fn.17) also termed the way that reality is not under human control in terms of resistance. How can we make sense of this kind of event without adopting scientific realism? In the Aristotelian scheme this chaotic behaviour and resistance is an example of *hyle*.

It is through the movements of the craftsman that materials are changed into products. These movements impose shape (*morphe*) and form (*eidos*) into *hyle* and produce substance (informed and shaped *hyle*).[2] *Hyle* is unknowable and incognate formlessness (*agnosis*).[3] The *techne* of making is the inscription of form into *hyle*. *Hyle* is the formless potential to receive form that is active in the reception of it. There is a definite limitation to the extent that *techne* can guide the shaping and informing of *hyle*; it is only to the extent that *hyle* can be grasped by "the rational part of the soul", as form (*eidos*), that it can be known (and consequently a part of *techne*).[4] Every *technai* has its appropriate forms, tools, and materials. These materials, tools, and forms govern the making (poiesis).[5] Although the form is in the mind of the craftsman, its union with *hyle* is partially directed by *techne* and partially directed by *hyle*. The extent to which *hyle* can be informed and shaped is not entirely in the control of the craftsman. S/he must attend to *hyle*. Form cannot be imposed upon (forced into) *hyle* and the craftsman must be responsive to the way that *hyle* receives form. It is for this reason that Aristotle argued that both *techne* and perception are necessary to guide the practices of making.[6] The craftsman must attend and be responsive to the capacities and tendencies of *hyle* that arises from the particularity of materials as experienced by the craftsman as s/he attempts to produce the object appropriate to her/his *techne*. No two lumps of clay are identical.[7] *Hyle* is the particularity of any particular lump of clay. *Hyle* gives particulars their particularity. Aristotle defined *hyle* as *the particularity of the particular*.[8] A potter cannot make the same pot twice; each experience of making a pot is particular and each crafted pot is particular. This emergent particularity is *hyle*. The *hyle* emergent during production would not occur without the initiation of production, but it is the *hyle* that prevents the craftsman from having complete control over the production process and the form of the final product. The

[2] *Gen. An.* 1.22.730b10-20

[3] *Meta.* 7.9.1034a10-11

[4] *Physics* 2.2.194a23

[5] *Meta.* 7.9.1034a10-11

[6] *N.E.* 2.9.1109b23. Note that perception is not limited to sight. In fact, for Aristotle, touch is an essential mode of perception.

[7] Note that *hyle* is not the clay. Clay is a *substance* in virtue of being informed *hyle* (given the form of clay). *Hyle* is the particularity (the individuality) of any one particular lump of clay.

[8] *Meta.* 7.8.1033b20-1034a7

word *hyle* captures something of Pickering's term "material agency" because it is emergent through productive practices. It also captures something of Gooding's phrases "the participation of Nature", "recalcitrance", and "plasticity" in his description of the development of craft practices in the early experiments by Faraday *et al.* Due to *hyle*, individuals cannot be known in their particularity through the general *logos* of *techne*. No general principle is capable of being applicable to all particulars and there are no universal statements that are always correct. [9] It is *hyle* that prevents any *techne* from being completely characterised by a complete set of rules (or instructions) that can be verbally transmitted from craftsman to apprentice. *Logos* is necessary but not sufficient. Although *techne* is comprised of formal, communicable, general, and abstract, principles of making, it is primarily learnt through imitation and attending to the particularity of the appropriate materials.

According to Heidegger (1939, pp.209-10), the term "appropriateness" also gives meaning to the term *hyle*. In ordinary Greek *hyle* meant forest, thicket, or woods, in the sense of a place for hunting and gathering material for building. From this ordinary meaning, *hyle* came to mean material for any and every kind of building or production. However, *hyle* did not mean raw material. It meant the capacity, or the appropriateness, for use in the construction of a product. The wood to make a table is selected and cut to order and, consequently, the very character of its appropriateness is decided in relation to the making of the table. It is in this sense that the properties of a natural entity, say a tree, are determined in relation to its appropriateness for a task of making. Thus the term *hyle* captures both the sense of resistance, or recalcitrance, and also the sense of appropriateness. However, we need more than this. What of the transformative power? To understand this requires further inquiry into the way that transformative powers are "brought forth" by the complex processes of experimentation.

The Theory of the Real:

In the case of experimental physics, I have used the word *techne* to characterise the objective asymptote of distinct strata of causal accounts of the applicability of techniques in the design, construction, operation, and interpretation of the performances of particular kinds of machine (i.e. mechanical, thermodynamic, electromagnetic, quantum, etc.), and show how the interconnection between these kinds, in terms of technical convergence and integration, leads to novel strata of kinds of machine. Thus magnitudes of measurements cannot be simply attributed as properties of the object measured; the magnitude of measurements must also be linked to the techniques used to make those measurements. It is for this reason that, given that scientific objects are defined in terms of "their" measurable properties, I have termed all such objects are *techno-phenomena*. Thus scientific progress, positivistically defined in terms of predictive success, is a matter of the increased technological enframing of phenomena into the "framework" of technique and bounded technical rationality. Thus empirical investigation is itself a manifestation of *Ge-stell* in which each progressive refinement of accuracy is a standing-reserve for the future challenging of the "technological framework" to become increasingly precise and exact. The objects and measurements of

[9] *N.E.* 5.10.1137b13-15

"empirical research" are bound-up with the destining of technique that cannot ultimately be satisfied because it has no end apart from itself as a means. It is itself an experiment into its own possibilities.

Modern physics simultaneously establishes itself and differentiates itself in its projections of specific object-spheres. The development of object-spheres (projection-plans) occurs by means of a corresponding methodology that is made secure via the rigorous application of procedure. This methodology is adapted and established, at any given time, in ongoing activity. Projection and rigor, methodology and ongoing activity, mutually requiring one another, constitute the essence of modern physics and transform it into research. The unity of this system is not contrived by relating object-spheres according to their content. Again Heidegger's analysis was correct but left crucial questions unaddressed. How was the unity of this system conceptually possible? How do the sciences achieve "solidarity and unity" upon this conception? How does planning provide this basis? How does modern science achieve and maintain conceptual unity, given its particularisation (specialisation) within institutionalised ongoing activity, if the unity of the system is not contrived by relating object-spheres according to their content? Heidegger was only able to account for the unity and performativity of modern sciences by appealing to the amenability of Nature towards the methodology of science and, therefore, he implicitly presupposed the unity and passivity of their object. For Heidegger (1977c, p.127), research calls Nature to account insofar as Nature "lets itself be put at the disposal of representation" and, consequently, is calculated in advance and "set in place" by research.[10] He explored the relation between modern science and culture in *Science and Reflection* (1977c) and critically assessed the view that science, together with its cultivation and organisation, is a part of culture (1977c, pp.155-82). In his view, science is given cultural value and is pursued by human beings from a variety of motivations. However, asserted Heidegger, we can not understand the essence of science and its scope if we take science as cultural only this sense. He asserted that the same holds for art. For Heidegger (p.156), science "is one way, and indeed one decisive way, in which all that is presents itself to us" and "is no more a cultural activity of man than art." Western European science determines the fundamental characteristics of the reality within which "man of today moves and attempts to maintain himself". Science has developed unprecedented power that is "ultimately to be spread over the entire globe". Heidegger raised the question as to whether science is "nothing but a fabrication of man" or whether "something other than mere wanting to know on the part of man" rules in science. Heidegger's intention, from the onset, was to reveal what this "something other" could be.

He started this inquiry by equating this "something other" with "a state of affairs" that reigns over all the sciences but is hidden from them. However, argued Heidegger, we need to adequately clarify what science is before we could bring this "state of affairs" into view. His starting point was premised upon the

[10] Lovitt noted (fn. 11) that "set in place" is a translation of *gestellt*. The verb *stellen*, with its meanings of to set in place, to set upon, to challenge forth, and to supply, is fundamental in Heidegger's understanding of the modern age. Heidegger used it to characterise the manner in which science deals with the real (1977c pp. 167-8) and the related noun *Ge-stell* characterised and named the essence of modern technology (1977a).

importance of a description of the scientific enterprise of our day that shows how the sciences have intersected with industry, commerce, education, politics, warfare, and journalism. Heidegger proposed that science should be situated within this description, as *the theory of the real*. What did Heidegger mean by this single concise statement? Heidegger elucidated "the theory of the real" by means of an etymological analysis. He analysed the modern conception of "the real" in terms of "that which works". The central question for modern science is: how does it work? In the modern conception of "the real", according to Heidegger, performing and executing became central to the setting-forth and self-exhibition of reality. It was this concept that allowed the factual to follow from "deeds and doings" whilst retaining the connotation of certainty. It was for this reason that Heidegger considered that the transformation of the conception of "the real" into "the certain" was characteristic of the post sixteenth century modern age. Henceforth, "the real" could be presented as present in the occurrence of consequences.[11] "The real" was presented in such a way that allowed it to be encountered and demonstrated, in terms of consequences, as an object. It is this characteristic of "the real" as "that which presences as object" which provided that kind of presencing characteristic of the modern age: *objectness*. (p.163) For Heidegger, how the objectness of that which presences was brought to appearance, and how that which presences became an object for representing, could only be understood in relation to theory. How is Nature, supposedly the object of modern science, presencing itself? What is the "itself" here? Heidegger noted that the fundamental conceptual change was that of conceiving of Nature in terms of its objectness.

Heidegger used *arbeiten* and its compounds (*bearbeiten*, "to work over or refine", *zuarbeiten*, "to work toward", and *unmarbeiten*, "to work around or recast") juxtaposed with *wirken* ("to work"), in order to set in place the performative way in which modern science brings "the real" (as an object in a causal sequence) into presence. Modern experimental science involves working towards and striving after reality in order to capture and secure it. Theory as *Betrachtung* meant capturing, entrapping, and secure refining of "the real".[12] In the experimental sciences "the real" is "what presences as self-exhibiting", refining it corresponds to a fundamental characteristic of "the real" itself, but its presence is brought forth to stand in objectness. Wrought by work, scientific theory challenges and sets-upon "the real".[13] "The real" is ordered into place as "an interacting network" of a surveyable series of related causes and, thus, is made into something that is capable of being followed out in its sequences. This secures "the real" in its objectness

[11] This meaning of "the real" was central to Bhaskar's transcendental arguments.

[12] Reminiscent of Popper's use the metaphor of the net to describe the use of theory. Heidegger was aware of the capacity of nets to let things pass through as well as trap things.

[13] Lovitt noted (p.167 fn 21, and pp.167-8 fn 22) that "challenges" translates *herausforden* (lit. demands out hither). "Sets upon" translates *stellen* (cf. *QCT* p.15 fn 4). Heidegger used the following verbs to characterise the conduct of modern science as theory: *nachstellen* ("to entrap"), *sicherstellen* ("to make secure"), *bestellen* ("to order" or "to command"), *festellen* ("to fix" or "to establish"), *vorstellen* ("to represent"), *umstellen* ("to encompss"), *erstellen* ("to set forth"), and *beistellen* ("to place in association with").

and provides object-spheres and object-areas for scientific observation to capture. The work of modern science is one of performing representational captures that refine "the real" in accordance with the objectness through which everything real is recast *in advance* into a diversity of objects available for representational captures. Heidegger's interpretation of experimentation as a performative labouring activity upon materials, as a process of making representations of reality through planned material practice, has parallels with the approaches of Hacking, Gooding, and Pickering. This approach can be seen in Francis Bacon's prescriptions for the "new sciences" and was central to the advance foundation of modern experimental physics.

For Heidegger, modern science, as the theory of the real, was not self-evident, nor was it merely a human construct. Modern science was essentially defined by the setting-forth of presencing into objectness, by Heidegger, but he did not provide any account of how this was conceptually possible. For Heidegger (p.169), the essence of science was "rendered necessary" the moment that this setting-forth occured, but that moment, and its possibility, remained mysterious. As I have attempted to show throughout this thesis, a closer phenomenology can reveal the possibility of this "moment", and its subsequent "necessity", to be the conceptual synthesis, the spirit of the enterprise, that I have termed mechanical realism. However, if we accept Heidegger's characterisation of theory, as a process of making secure a region of "the real" as an object-area by specifically mapping out in advance the possibilities for posing questions, then this still leaves crucial questions unanswered. How is this advance mapping possible? How is a region of "the real" made secure? In order to address these questions we need to examine how new phenomena emerge within an object-area. For Heidegger, every new phenomenon emerging within an object-area of science is refined to such a point that it fits within the normative coherence of theory. This view has parallels with Kuhn and Feyerabend. Heidegger maintained (p.169) that normative coherence is itself changed from time to time whilst objectness remains unchanged in its fundamental characteristics. This idea of changes in normative coherence has parallels with the notion of "paradigm shift" (as coined by Kuhn).[14] How does objectiveness remain unchanged? What are its fundamental characteristics in modern experimental physics? For Heidegger, if representing in advance is the basis for strategy and procedure then science is determined by pure theory directed towards the objectness of what presences. Thus the validity of classical physics was limited but not contradicted by modern quantum physics and relativity. Modern subatomic and space-time theory refined the object-spheres of their respective researches but did not invalidate them. The narrowing of the realm of validity was a confirmation of the objectness normative for the theory of Nature. How is the *what* of "the objectness of what presences" chosen in order to set-forth the objectness of "the real" in such a way that there is not any fundamental change in objectness between classical and relativistic quantum physics? According to Heidegger, it is Nature that "presents itself for representation as a spatio-temporal coherence of motion calculable in some way or other in advance" in accordance with theory (p.169).

[14] It also addresses the two-fold dimensionality of experimental science in Bhaskar's *RTS*. Changes in normative coherence corresponds to the "transitive dimension" whilst objectness invariance corresponds to the "intransitive dimension".

Nature, according to Heidegger, is clearly an amenable participant in the work of modern science. What is the Nature that presents itself in this way? Or, to be more precise, which parts of the world are taken to be instances of Nature presenting itself in this way? And, how is the temporal coherence of motion calculable in advance "in some way or other" for these parts? Heidegger maintained that modern science, by defining the real to be the measurable, provides a method that permits a decision regarding what may pass as science by limiting certainty and knowledge to the measurability supplied by the objectness of Nature and the possibilities inherent in the measuring procedure. What allowed the real to be defined as the measurable? How does Nature supply measurability? How are the possibilities of measurement inherent in the measuring procedure? Heidegger argued (p.170) that the methodology of science sets up Nature as an object of expectation. All objectification of "the real" secures and guarantees some coherence of sequence and order. Mathematics participates in this methodology by setting up, as the goal of expectations, the harmonising of all relations of order and "reckons" in advance with one fundamental equation for all possible order, and is not merely a reckoning by performing operations with numbers for the purpose of establishing quantifiable results. How does mathematics set up the harmonising of all relations of order? How is this set up secured and guaranteed in relation to the objectification of "the real"? Heidegger did not address these questions.

For Heidegger, modern science, as the theory of the real, is *necessarily* compartmentalised into departmentalised sciences because it depends upon the procedure that attaches to its method, and therefore must, if it is to secure its object-areas, delimit those areas and localise them into compartments. Novel procedures necessarily lead to the compartmentalisation of modern science. Investigation of an object-area must, in the course of its work, agree with the particular form and modification possessed at any given time by the objects belonging to that area. This agreement with the particular transforms the procedure of a branch of science into specialised research. Specialisation is not a degeneration of modern science but is, rather, the necessary consequence of it. How do objects come to belong to an object-area? How do objects come to have particular form and modification? How is agreement between the particular and investigation achieved? He argued (pp.170-1) that new scientific questions and specialisations occur through the "border traffic" across the boundaries between delimited object-areas. These boundaries provide the "source of a special impetus" that produces new questions and specialisation. However, Heidegger conceded that this "source" was itself enigmatic and, consequently, so was the essence of science. According to Heidegger, the "inconspicuous state of affairs" which conceals the essence of science can be revealed by taking particular sciences as examples and attending specifically to whatever is the case regarding the ordering, in any given instance, of the objectness belonging to the object-area of those sciences (p.171).[15] For Heidegger, physics (in which he included macrophysics, atomic physics, astrophysics, and chemistry) observes Nature insofar as Nature exhibits itself as inanimate. Nature is observed in its manifestation as the objectness of coherence of motion of material bodies. The elementary objects of classical mechanics were

[15] Lovitt noted (fn.25) that "state of affairs" translates the noun *Sachverhalt* but a more literal rending would be "relating or conjoining of matters".

the motions of geometrical points, in nineteenth century physics these objects were fields and atoms, and in the twentieth century the interaction of elementary particles is the manifestation of the "impenetrability of the corporeal" (pp.171-2). However, an understanding of the "source of special impetus" is essential for an understanding of modern experimental physics. How do the boundaries between object-areas produce this "special impetus"? What is transferred in the "border traffic"? How are new questions and specialisations produced? Heidegger, by generalising from Galileo's *Assayer*, Newton's *Principia*, and Heisenberg's positivistic interpretation of quantum mechanics, had not attended to modern experimental physics closely enough, and, consequently, was compelled to consider the source of novelty and the essence of modern physics to be enigmatic. However, if we attend to how experimental physics is actually done, and what it is actually done to, then we can attend to the specific ordering of the objectness belonging to particular object-areas of physics *without preconceiving, from the onset, the nature of the object of that pursuit.* Throughout this thesis, I have attempted to show that this object-area is strata of machines, techniques, and their associated techno-phenomena. The laws abstracted from the alethic modalities[16] of the contours of machine agency are techneic. They are the produced results of exoframed labour processes.

Heidegger was correct to locate epochs of change, such as the change from classical physics to quantum physics, in the experience and determination of the objectness of the appropriate object-sphere, whilst emphasising that the essence of modern physics remains unchanged. However, for Heidegger, "in the most recent phase of atomic physics" the object vanished. Heidegger (p.173) alluded to a change in the objectiveness of Nature into "the constancy determined from out of Enframing" and made reference to *The Question Concerning Technology*. Heidegger noted, in reference to the Wilson cloud chamber, the Geiger counter, and the balloon flights to detect mesons, that modern subatomic physics, despite its aim to make elementary particles exhibit themselves for sensory perception, can only provide indirect, via a multiplicity of technical intermediaries, self-exhibiting of elementary particles. It is this indirectness which Heidegger alluded to as being indicative of the dominance of *Ge-stell*, as a fundamental change in the experience and determination of objectness, in the most recent phase of physics. Unfortunately he did not discuss this further. I agree with Heidegger's characterisation of modern physics as a mathematical projection of a ground-plan of the objectness of motion and his emphasis on work in the capturing of representations of Nature. However, by presuming that the object of experimentation in pre-quantum physics was present to perception, Heidegger revealed his bi-partite structure of experimental physics in terms of law-object. Given that, for Heidegger, law is something that we project over the phenomena in terms of cause-effect relations in order to map out the changing of the changeable, then the objects of investigation remains those aspects of Nature that are amenable to this project. It is an implicit consequence of Heidegger's analysis that the progressive criterion for selection of law could only be one of empirical adequacy of the laws description of the cause-effect relations to the changing of the changeable within the object-sphere. Thus Heidegger marked out "the most recent phase of atomic physics" as something distinctly given over to *Ge-*

[16] These are the determinations of the estimated possibilities, actualities, necessities, impossibilities, and contingencies of the reproduced interactions between human interventions and machine performances.

stell because the objects of its object-sphere are unavailable to direct perception. Heidegger's interpretation of the aim of experimental physics as being directed towards the mathematical projection of law describing the coherence of motion of its objects, and the constancy of the changing of the changeable, betrays his positivistic conception of science in general and physics in particular. In essence the aim of science, on Heidegger's account, is that of empirical description in terms of universal law. This should be unsurprising, given that Heidegger's two exemplars of scientific endeavour are Newton and Heisenberg, and that in Germany, at the time of Heidegger's writing, positivism was the dominant conception of science. I am not suggesting that Heidegger was a positivist (far from it!) but his conception of the goal of science was positivistic. Thus, for Heidegger, the object disappears in subatomic physics because it can not be directly revealed to sensory experience. However, the aim of modern experimental physics has always been the disclosure of mechanisms, and its ontology has had a tri-partite structure (object, law, and mechanism) since the sixteenth century. Particle physics is unconcerned with the detection of "particles", mesons for example, except as a means of investigating its models of elementary particle interactions. Physicists do not seek the "truth/top quark" for its own sake but, rather, for the disclosure that success would bring. Mechanisms have never been brought into presence, as objects, but are central to causal explanations for "that which presences". Here we can readily see how Heidegger's own phenomenological pre-occupation with "that which presences" obscured his view of the phenomena of experimental physics. Since Galileo, physics has had pretensions towards a "deeper" ontological relation with the mapping of temporal successions of cause-effect sequences than merely confirming or refuting the law. These explanations are given as the underlying workings of that which allows "that which presences" to presence. Is "the real" properly an object or a mechanism? If "the real" was demonstrated in terms of the temporal sequences of cause-effect relations, as Heidegger claimed, then such sequential relations are characteristically phenomenal. "The real", brought into discourse through the reality/appearance distinction, is more characteristic of the mechanisms that are proposed to *link* causes to effects and is not characteristic of the phenomenal. Thus the objectness of "that which presences" is taken to disclose "the real". The objectness of the object-sphere and the constancy of the changing of changeable are means to the disclosure of "the real" as a mechanism of change. Modern experimental physics requires an appearance/reality distinction in which the object-sphere, procedure, methodology, and mathematical projection are tied together via a model of the mechanisms in operation in the changes of the changeable. It is the mechanistic model that allows mathematical projection, the object-sphere, methodology, procedure, law, and the ongoing activity of working towards securing representations, to fit together as a coherent process of research. Working novel experimental physics is not limited to sensory experience but, rather, explores what is *disclosed by means of sensory experience*. Its object-spheres, object-areas, procedures, laws, advancing methodologies, and mathematical projections, have always been *means to this end*, and, in this respect, it changes the changeable in the object-sphere to suggest causal mechanisms which are "tested" by implementing them in the ongoing technological procedures of experimentation. Thus the use of objects as standing-reserve available for future use and ordering has been central to experimental physics since its onset. *Ge-stell* has been characteristic of modern experimental physics since its origins in the science of mechanics. *Ge-stell* has been operational within the unfolding and ordering of the ontology of experimental physics in all of its object-areas (i.e. mechanics, optics, thermodynamics, electromagnetism, acoustics, solid state physics, atomic physics, and subatomic physics) and is not restricted to the "most recent phase in atomic physics". Heidegger's positivistic conception of modern science concealed the operation of *Ge-stell* in experimental physics and, consequently, concealed the technological essence of modern experimental physics.

What Heidegger misunderstood is the objective of the pursuit of experimental physics. Experimental physics does not pursue the objects of its object-spheres, nor its object-areas, nor the "objectness of Nature". Heidegger was correct to have considered objectness to be essential to the setting up of modern sciences in general and modern physics in particular, as a methodologically and procedurally secured mathematical research projection of the ground-plan of its object-sphere. Modern experimental physics could have not begun nor operate without this set-up. However, we need to look closer than Heidegger did and actually attend to the original object-sphere of modern experimental physics. This object-sphere was the six simple machines: the wheel and axle, the wedge, the lever, the inclined plane, the screw, and the balance. Each one of these machines is the material exemplar of a mechanical motion, this object-sphere was *the first machine-family*, and the mathematical project of mechanics was to determine the fundamental principles of their motions. The mathematical science of mechanics provided the "template" for all subsequent physics. The object of experimental physics is *machine performativity*, whether a pendulum or neutrino detector, and that this object could only be conceived *as natural* by presupposing mechanical realism. Particular specialisations in experimental physics have distinct machine-kinds as their objects. The ontology of experimental physics is limited to machine performativity, kinds, and families. Particular specialisations are delimited by specific machine-families, and that novelty and new specialisations arise from the innovative interconnection (the relating and conjoining) of machine-kinds. On this account, the function of an object-sphere is *to disclose the fundamental mechanisms* that generate the cause-effect relations actively produced and investigated by modern experimental physics. Modern experimental physics is only concerned with the motion of matter *insofar* as it discloses those fundamental mechanisms. In order to understand this disclosure we need to attend the nature of mechanisms and power.

Mechanisms and Power:

Bhaskar stated that things possess powers and liabilities in virtue of their internal structure (1975, pp. 87-90). He adopted a Lockean notion of "real essences" in his claim that its microstructure or internal constitution determines the powers of a thing.[17] His notions of "power unrealised" and "power unexercised" rest upon this notion. Bhaskar defined a power as unrealised when the power of something to act in a certain way is thwarted by the power of another thing. He defined a power as unexercised when a thing is not in the context in which it can exercise its power. Bhaskar identified power as belonging to the thing in question and, thereby, had an atomistic conception of power. He used this conception to identify the

[17] Cf. Locke, J., An Essay Concerning Human Understanding, III, III, 13.

essence of a thing.

"Dogs cannot fly or turn into stones, but they can move around the world and bark in all kinds of ways." (1975, p.112).

However, by identifying "moving" and "barking" as the powers that identify the essence of a dog, Bhaskar used an Aristotelian schema. This is at odds with Locke's definition of real essence. Aristotle's definition of a thing's essence as "being what something is" in virtue of the matter of that thing possessing a certain form.[18] The identification of the essence of a thing, as an empirical problem, involved the identification of which characteristics are essential in the sense of being causally fundamental to the identification of that thing as a member of a specific kind. This was not done in terms of a microstructure, or hidden reality, but was done according to the phenomenal appearance of a thing. The characteristics of barking, moving, four-leggedness, etc., were clustered as a multiplicity of characteristics for the purpose of classifying an individual as a member of a species. The classification of an individual as a dog involves an assertion of a set of normal canine characteristics within an environment that is taken to be natural for dogs. The dogs involved in the Soviet space program not only flew but also reached an orbit of the Earth. The dogs of the Palaeolithic on display in museums have petrified into stone. Dogs cannot bark in a vacuum or underwater. They cannot move around the world when they are caged or trapped in a box. Bhaskar, by associating barking and moving as the powers of dogs, was simultaneously asserting a normal environment for dogs to be in and a normal set of interactions within that environment. By doing this, he had not only presented an atomistic account of power but had also hidden an account of a normal existence for certain kinds of being. My objection to Bhaskar is not that he had presumed that outer space is not a natural environment for a dog. My objection is the hidden appeal to norms that Bhaskar attempted to use to rhetorically move from dogs to a general account of power in terms of mechanisms. This arbitrarily asserts conventions and pre-empts the scientific inquiry he advocated. In Locke's terms, Bhaskar identified a "nominal essence" as a "real essence". Such statements are merely a conventional association of the predicate of a sentence as the property of the subject. Bhaskar's normic and atomistic association of powers are merely a consequent of standard uses of language and do not, necessarily, reflect any natural order of things (except via assertion). They are an example of *episteme*, in Foucault's (1994) sense. Such statements reflect how Bhaskar substituted a transitive dimension of certain language structures as an intransitive dimension of "Nature". This is an expression of the extent that he is a prisoner of the thought of the past. He does not provide any necessary nor sufficient reason why we should follow suit. We can interpret power as contextual and the power of dogs to bark, move, turn into stone, or fly, arises through the contexts in which dogs are agential participants. Bhaskar attempted to describe the things of open systems, i.e. dogs, in terms appropriate to the things of closed systems, i.e. mechanisms. Bhaskar attempted to simultaneously adopt an Aristotelian empirical analysis of the phenomenal characteristics of things in their natural environment *and* a Lockean

[18] *Meta*, Z IV - Z XVII

analysis of things in terms of their internal mechanics.

If things exercise and realise powers and liabilities in virtue of the contexts in which they are situated, as Bhaskar claimed at first, then his attribution of powers to the things themselves was contingent. If the attribution of powers and liabilities to things is based upon their possible interaction, and possible outcomes, with other things, as Bhaskar later claimed to recognise (p.88), then it was arbitrary to attribute powers to the things themselves rather than the interaction between things. If the powers are attributed to the interaction between things then there can be no notion of either "power unrealised" or "power unexercised" because both of these are merely statements of the absence of any empowering interaction. They are reconstructions. For example, the power of a hydrogen atom to combine with a chlorine atom, under suitable conditions, to produce a molecule of hydrochloric acid is not, as Bhaskar claimed (p.109), necessarily a property of the "internal electronic structure", but is, alternatively, a property of all the agents involved in the interaction. This will include the presence of a hydrogen atom, a chlorine atom, and the suitable conditions. It will also include all the conditions in virtue of which hydrogen and chlorine atoms exist and are brought together. It is a power of the whole process of reproduction, from beginning to end. Thus we do not need a notion of "power unexercised" to describe the inability of hydrogen to produce hydrochloric acid when chlorine is absent. Nor do we need a notion of "power unrealised" to describe the inability of hydrogen and chlorine to produce hydrochloric acid if the conditions are unsuitable for the reaction. Hydrogen has no power to produce hydrochloric acid at all. Only the whole interactive process of hydrochloric acid production has this power, and hydrogen is only an agent in this process. Hydrogen has no power, exercised or unexercised, realised or unrealised, in isolation, as an atom. By adopting a mechanical conception of essence, Bhaskar defined the is-ness of a thing is defined in terms of what that thing does. Thus the being of any thing is de-limited by its productive agency in context, and the knowledge of a thing within a context of production is techneic rather than epistemic. Given that hydrogen is only identifiable *qua hydrogen* in virtue of what it repeatably does in certain kinds of interaction then it has no identity in isolation. Can we say that something without power, without identity, exists? Not on Bhaskar's mechanistic account. In my view, this forced Bhaskar's hand. He rhetorically stepped outside his mechanistic account in two ways to preserve his mechanistic account. Firstly, he defined an entity in terms of what it has the *potential* to do. Secondly, he defined a set of normal conditions in which an entity would exercise its potential. However, by insisting that the potentials of entities were to be determined by experimental science, he has presented the closed system *as if it were the normal conditions* of an entity. Thus how an entity is revealed by science is how the entity truly is, if it were not for the interference of other entities in the messy open system. However, this causes Bhaskar serious problems. If something, say hydrogen, is identified in terms of what it repeatably does in certain kinds of interaction, and repeatability (as a deterministic regularity) only occurs within closed systems, as Bhaskar claimed, then without the notions of "power unexercised", or "power unrealised", then objects, such as hydrogen atoms, cannot be said to exist in open systems at all. When we claim that we detect the presence of hydrogen in an open system, we have, in Bhaskar's terms, subjected the open system to closure by using the artificial closed system of the detection apparatus. The detection of hydrogen requires certain kinds of interaction to take the form of constant conjunctions. This may at first sight seem strange but the power of a hydrogen detection device to detect hydrogen in an open system is not simply a matter of hydrogen being present in the open system. It is characteristic of an interactive technological process of closure in terms of a deterministic confirmation or denial of the existence of hydrogen according to an anticipation of what the detectable properties of hydrogen are. This is itself a productive process. The interactive behaviour of hydrogen, its is-ness, is dependent upon what it interacts with, if we adopt the mechanists' view. The identity of hydrogen is dependent upon a context in which hydrogen can only be said to be a participant. The term "hydrogen detection" is an index for a set of interactions within that context. It can only be said to have transcontextural identity, transfactuality, to the extent that its contexts of interaction have a shared set of participants. The contexts of using hydrogen in the production of hydrochloric acid and as the nuclear reactant in fusion bombs are taken to be independent because the processes of the industrial extraction and production of quantities of hydrogen, required by both chemical and nuclear utilisations of hydrogen, and the shared hydrogen identification instruments used to check purity, are not taken into account. Once we take the shared production processes and identification instruments into account then we can see how the so-called "independent contexts" are, in fact, historically and technologically related via machinic agency. The transcontextural, or transfactural, identity of hydrogen is a product of concealing the shared processes and instruments within the so-called "independent contexts". The transcontexturality arises by concealing the overlapping of technological enframents and machine-kinds. Furthermore, the processes of hydrochloric acid production, <u>in closed systems</u>, require technological processes for their empowerment. Thus the power to produce hydrochloric acid is a property of these technological processes, within which hydrogen and chlorine are agents. These technological processes empower the mechanised interaction of agents, including human interventions and machine performances. The power to produce hydrochloric acid arises through the interaction of all these agents and cannot be isolated from the context of interaction. It is a property of the technological enframent that brings together and interacts these diverse agents.

Bhaskar's account of power, causes, and mechanisms in open systems may well provide the conventional structure of a realist theory but it does not, in practice, provide us with any method by which we can identify which are necessary and which are apparent (i.e. the effects of "deeper" causes, powers, or mechanisms). To use Bhaskar's examples, an unhappy childhood or a stray bullet (p119) are only identifiable as causes in hindsight, by isolating them from the phenomenal continuum of existence. This kind of isolating act is both artificial and arbitrary because (1) such "causes" are simultaneously "effects"; (2) we cannot know whether such "causes" were actually responsible for the "effects" that we ascribe to them. We can unpack the "causes" of any phenomenon as the "effects" of other "causes" *ad infinitum*. The unhappy childhood may have been caused by the parents' neglect of the child or the stray bullet may have been caused by the distracting effect of the bark of a dog, etc. These other "causes", in term, can be unpacked as "effects" of further causes. The parents' neglect of the child may have caused by their unhappy marriage or the bark of the dog may have been caused by the presence of next door's cat, etc. There will also always be a plurality of possible alternative "cause-effect" sequences for any phenomenon. The unhappy childhood may have been caused by the child's own lack of self-worth, the stray bullet may have been caused by the gunman's own fear of dogs, etc. In total, the cause-effect structure of any phenomenon is a non-linear structure without scale: an infinite pluralistic continuum of imaginable possibilities. We are faced with an indeterminate chaos of possible "causes-effect sequences" for any phenomenon in open systems. The action of a closed system is to produce an actual "cause-effect sequence" from this indeterminate chaos. It is arbitrary to take the single resultant chain as the only possible one. Furthermore, due to the unrepeatability of phenomena in open systems, each "cause-effect sequence" will be temporarily open, dynamic, and incomplete. We cannot have any law-like knowledge of the causes of the phenomena of open systems. If we resort to claims of plausibility for any single "cause-effect sequence", in open systems, then we are no longer proposing "necessary connections" but "probable connections" instead. However, the establishment of "probable connections", as an establishment of likelihood, can only be made with reference to the expectations of a social group, and, as such, is made rhetorically in terms of the experiences and prejudices of that group. "Probable connections" are not universal and their establishment is a local social construct. A different social group, with different expectations, will have a different estimation of the likelihood of any "probable connection". Furthermore, "probable connections" are themselves the product of the reconstructive analysis of the history of the phenomenon in question. We should not divorce the agencies brought together to perform that analysis from the products of that analysis.

Bhaskar maintained that the identification of "mechanisms" must be left to the experimental sciences. Mechanisms, by definition, are indices for the repeatable processes by which a cause generates effects. On my account, these can only be identified in closed systems and are restricted to the artificial contexts of experimental sciences. Bhaskar did not provide us with any reason why we should believe that "mechanisms" occur in open systems at all. By the qualification that they are "repeatable", a quality denied by Bhaskar to the phenomena of open systems, there are good reasons why "mechanisms", even by Bhaskar's account, could be taken to only occur in closed systems. My argument is that "mechanisms" are ontologically restricted to the kinds of machine-families and productive contexts in which they occur. They are technological objects and do not necessarily occur in Nature at all. They are the products of a technoscientific process that is itself empowered through its non-linear relations within the wider world. Once the technoscientific character of the experimental sciences has been addressed then the realist notion of "causal power" is open to the criticisms that it is overly simplistic, culturally situated, uncritically supportive of the status quo, and reactionary. It is the reification of technique as neutral and normal. The inter-relationships between technosciences, and the wider world, in which they are situated, need to be analysed in terms of *complexity* rather than causality. This approach attempts to situate the modern experimental sciences within "the big picture" and phenomenologically understand modern science from within as broad a social and historical perspective as is possible. Science, technology, human agency, and human experience (in the technoscientific cultures and societies of the current era) permeate and penetrate each other to such an extent that it is impossible to separate them. The relationships between technoscience and the world in which it is situated are understandable in terms of non-linear "feed-back" loops in which both are defined and transformed in relation to the other. Modern science legitimates and circumscribes definitions of "Nature" whilst being legitimated and circumscribed by society, culture, technology, human agency, and human experience. These definitions of "Nature" are then used to legitimate and circumscribe science, technology, society, culture, human agency, and human experience. On my account, the primary relationships between scientific discourse and "Nature" are reproduced relationships of power and agency situated within a mechanistic world-picture. The scientific attempts to identify "truth", "efficiency", "natural law", and "causality", are attempts to reproduce techniques, interpretations, practices, values, dogma, institutions, orthodoxy, and authority, through acts of closure and the exercise of social power, in the face of contingency, plurality, controversy, and chaos. They are attempts to impose order upon the world.

The directions of scientific research have been bound up with political, commercial, and military ambitions since its beginning. Physicists have contributed to the development of military technologies from the sixteenth century Venetian Arsenal to the twentieth century Manhattan Project. The "big science" projects, such as CERN, are only possible because of massive international co-operation and the development of the "atom-splitting" technologies of military weapon research and civilian electricity generation.[19] Research projects are selected and shaped by the criteria of nation states, industries, religious groups, corporations, bureaucracies, universities, entrepreneurs, and military planners. They are chosen according to estimations of their value, productivity, feasibility, and results, by the groups that provide the resources required for those projects. They are selected and shaped according to the criteria of social interests and are dependent upon social structures, agencies, and powers for their existence. The realist notion of scientific rationality is not easily sustained once we address the extent that technosciences are embedded in trans-scientific fields of *Ge-stell*. The claim for the rationality, truth, and universality of the technoscientific enterprises of *Ge-stell* is simultaneously a claim for the legitimacy, power, and globalisation of *Ge-stell*. It is for this reason that scientific realism has been heavily criticised by social theorists, political theorists, psychologists, phenomenologists, and philosophers.[20] These writers largely

[19] See Galison (1987) and Krige (1989) for historical accounts of the development of experimental physics at CERN. I would like to add that the CRAY supercomputer used to process the massive amounts of data generated by the CERN detectors (ALEPH, OPAL, DELPHI, and L3) is itself a product of US military research.

[20] Cf. Gordo-Lopez & Parker (1999); Stiegler (1998); Aronowitz *et al.* (eds.) (1996); Pickering (1995, 1992, 1987); Adorno (1994); Fuller (1993); Street (1992); Haraway (1991, 1989); Ihde (1991, 1983, 1979); Latour (1991, 1987); Jamison (1989); Yearly (1988); Bijker *et al.* (eds.) (1987); Habermas (1987, 1971); Elsea (1986, 1983); Harding (ed.) (1986); Ince (1986); Kenny (1986); Marcus (ed.) (1986); Jonas (1984, 1974); Hughes (1983); Baudrillard (1981); Knorr-Cetina (1981); Levidow & Young (eds.) (1981); Latour &Woolgar (1979); Durbin (1978, 1972); Winner (1977); Horkheimer (1974); Hall (1972); Mathias (1972); Mathias (ed.) (1972); Greenberg (1967); Gadamer (1966); Marcuse (1966); and Arendt (1958).

present themselves as directed towards the development of free and just human relations within the technoscientific cultures of Western Civilisation. They have taken an ethical stance against the dominance of technosciences within modern society and culture, because they hold that Western Civilisation is an inherently unjust and dominating mode of social organisation because of its obsession with power and advantage. Their critiques of science and technology are effectively moral critiques. These writers identify the technoscience of physics as an historical, cultural, and moral phenomenon, that can not be isolated from the contexts and trajectories in which it is embedded and emergent from, and can not be considered as ethically neutral. It is from within this "tradition" that I wish to situate this thesis. However, in my view, if we aim to understand how experimental physics, as a "technoscience", has achieved the status of a "natural science", then we need to understand how science and technology have been "internally" connected through the mathematical science of mechanics. This is evident in Locke's notion of primary and secondary qualities. This distinction is itself a product of the technological enframent of phenomena. That which can be mechanised and mathematically abstracted is considered primary, objective, and part of non-human nature. That which can not is considered secondary, subjective, and part of human nature. This distinction is itself a technological enframent of human thinking which transforms the limits of machines and mathematics into the boundaries of Nature and human psychology. This establishment of a dualism between the objective and subjective is a metaphorical de-centring of the relations between humans and machines. Once Nature was reduced by this technological enframent then the nonhuman nature of machines could be presented as the nonhuman nature of objective pre-scientific reality. This move is itself the two-fold process of reification of machine performances into idealised mathematical abstraction and the subsequent removal of the machine from the account. This leaves us with the writing on "the Book of Nature". All models in physics are based on the conceptual instrument of mechanisation, the mechanisation of Nature, and consequently models are seen as essential tools for describing the processes of Nature; and consequently, the central question in modern physics is: how does Nature work? This is the "intransitive dimension" of physics.

It is this approach that reveals the extent that *episteme* has been transformed by modern physics in order to be presented as a *techneic answer* in terms of general and abstract causal principles which take the form of mathematically abstracted mechanisms. The centrality of this question to modern physics reveals the extent to which *techne as a directional principle and episteme as a directional principle have converged. Techne* has become exoframed and *episteme* has become mechanised. The distinction has been shifted by the historical development of *epistemic techne* and *techneic episteme*, where the former is the knowledge of mechanical principles involved in an experiment and the latter is the knowledge of mechanical principles of Nature itself. The single point of distinction between these two is that the former has the experimenter as the efficient cause and the latter has "the inner workings of Nature" as the efficient cause. The work of modern physics is to generate a praxis that removes the experimenter from the account. What is left is then taken to be non-human Nature. This work can be done because nonhuman Nature has been constructed as the mathematically abstracted workings of nonhuman machines. This is the methodological work of mechanical realism. The machines themselves, through mathematical abstraction, have been removed from the account and the transformed *techne* is presented as *episteme*. What has made this transformation possible? This transformation is possible because the nature of *episteme* was historically pre-empted and *techne* and *episteme* have been treated as metaphors for one another. This pre-emption allowed two important desires to be offered a source of satisfaction. The first was the possibility of a comprehensible world picture of the world, human beings, and how human beings are situated in the world. The second, was the promise of novel experiences and novel powers as the fruit of human labour and skill at making. The mathematical science of mechanics offered the second; the mechanical world-view promised the first. Furthermore, the conflation between *techne* and *episteme* in experimental physics is the transformation of the ideals of the human character: the Baconian dream for the human character was that of a rational material agent whose primary function was to labour, and whose reward would be new powers and new challenges for labour. Heidegger argued (1939, p.220) that modern science treats *phusis* as if it were a self-making artifact and has been interpreted as if it were a kind of *techne*. Heidegger posited that this interpretation of *phusis* is a consequence of the modern metaphysical conception of the essence of "nature" as a "technique". For Heidegger (1999, p.259), the essence of materialism does not consist in the assertion that the world is exhausted by the physical interactions between particles of inanimate matter, but, consists in a metaphysics that reduces every being to a material available for labour. The articulation of this metaphysics was anticipated, according to Heidegger, in Hegel's *Phenomenology of Spirit* as the self-establishing process of unconditional production, experienced in human existence as subjectivity, is the objectification of the actual. The essence of materialism was concealed by the essence of technology, *Ge-stell*, and, as a derivation of *techne* as a mode of *aletheia*, is a form of truth and rendering beings manifest. As a form of truth, modern technology is grounded in the history of metaphysics. Heidegger wrote

"The greatest care must be fostered upon the ethical bond at a time when technological human beings, delivered over to mass society, can attain reliable constancy only by gathering and ordering all their plans and activities in a way that corresponds to technology." (1999, p.268)

This still leaves us with the question of what *is* a technological human being. To that end, we need to take a closer look at artifice itself. What is artifice?

The Meaning of Artifice:

If we treat technology as the making and using of tools, techniques, procedures, materials, resources, skills, and machines, as means to ends, as embodied in our everyday practices, then it is largely an unreflective activity. Technology largely remains an unattended to preconscious background, directed towards unreflected-upon ends, that produces and manipulates unreflected-upon objects. Put simply, any technology is a collection of tools, techniques, procedures, materials, resources, skills, and machines. Artifice is the skill of how and when to use specific technologies in order to manipulate things in the world to achieve specific desired goods (or ends). Artifice is skilled technology use. We largely take it for granted. By embodying artifice, human beings are enframed by, and immersed in, technologies that extend beyond the individual human body. Technologies are socially organised structures that, through the embodiment of artifice, are integrated into the agency of the individual human body and organise that agency. Artifice involves acts and effects of inscribing and making.[21] Inscribing is an act of writing, carving, drawing, marking, or measuring. Making is an act manipulating things in the world to bring other things into the world. Artifice involves a spatial and temporal ordering of productive practices, in order to effect change, transform things into other things, and brings things into the world. Artifice enframes material practices, inscriptive practices, materials, and human bodies. It is an ordering structure that directs the practices through which things are brought together, arranged in temporal and spatial sequences, and transformed into other things. Artifice is effective through being embodied in human activities involving materials and inscriptions. In order to become technological, a human being must embody the material and inscriptive practices that artifice imposes. The motility and intentionality of the body is enframed by the template of artifice. The would-be skilled practitioner must learn how to use specific tools to perform specific activities, upon specific materials, to transform those materials into specific products. S/he must also learn how to use specific tools to perform specific inscriptive activities, upon those specific materials, as part of the productive processes of the artifice of carpentry. By habitually embodying these activities in practice the would-be skilled practitioner becomes a skilled practitioner and is empowered to make specific products. The process of embodiment of the enframent of practices upon materials is an embodiment of the discipline/power of artifice. The discipline/power of artifice generates productive human agency *qua technological human being* upon specific things in the world. Human agency *qua technological human being* is directed, through embodied artifice, towards a horizon of specific ends or goods. The process of transformation of specific things into other specific things *brings things that did not exist before* into the world. Embodied artifice upon materials towards a horizon of specific ends is a process of *poiesis*: bringing entities forth into the world. It is this that for Aristotle, and Heidegger, related *techne* to *phusis*. *Techne* "brought forth" the object through the agency of the craftsman upon the materials. *Phusis* "brought forth" itself without the aid of the craftsman. *Phusis* was bringing forth in the highest sense, for both Aristotle and Heidegger.

Tools are extensions of the body.[22] Tools extend the controlling organ, or limb, of the human body; they are an "organ projection".[23] This extensional relation between tools and the human body has existential import upon human agency in terms of power, identity, and the horizon of our *poietic* possibilities. Tool use has to be learned. The controlling organ, or limb, must be disciplined to use a tool

[21] The etymology of artifice is from the latin *artifex*: one possessed of a specific skill. This derives from *ars* (skill) and *facere* (to make). [OED]

[22] Cassirer (1928), Kapp (1877), Emerson (1860), Aristotle (*Eudemian Ethics* 7.9.1241 b24), Ihde (1979, 1983).

[23] Cf. Kapp (1877, pp. 44-5) for a discussion of the idea of "organ projection"..

effectively. Human agency is both constrained and empowered through extension. Discipline/power are the Janus-faces of artifice. Tools achieve their effectiveness through labour.[24] Tools amplify and reduce human experience and capabilities by shaping the embodiment relations in which they gain their effectiveness. Hammers amplify the agential power of the human hand by reducing its motile freedom, sensitivity, and softness. Microscopes and telescopes amplify the perceptive potentials of the human eye by reducing the depth and breadth of vision. Tools exchange increased power for the naturalness of the human experience. They extend human manipulative power and the field of material practices for achieving specified ends. By constraining and empowering human agency, artifice channels and extends human agency towards an otherwise unobtainable horizon of possibilities. Artifacts, such as computers, measuring instruments, and maps, organise and order technographe to extend the human capacity to manipulate, record, and visualise abstractions. Instruments, such as thermometers and weighing scales, organise and order parts of the world in terms of abstract quantities. These devices are effective in virtue of being embedded in a set of interpretive and inscriptive practices.[25] The human cognitive imagination is enhanced and channelled as technologies extend the human capacities for intellectual agency at the expense of absolute freedom of thought. The human agent can exert considerable creativity and free play when using these technologies only to the extent that s/he acquires the appropriate artifice for achieving specified ends an otherwise unobtainable horizon of projected alethic modalities.

Artifice provides an otherwise ineffective and undisciplined body with agency and intentionality. The existence of specific artifices permits the existence of specific intentions. Artifices provide us with both means and ends. They shape intentionality and agency by shaping the horizon of possibilities available to us, as well as the ways of reaching that horizon. It is this set-up of this shaping that Heidegger refered to as *destining. Ge-stell* is involved in what it is to be a technological human being. Human life entails an *interactive* relationship between intentionality and artifice, and, consequently, "human nature" is not given by "Nature" but is created by disciplined and empowered agencies. Human life is projected beyond "organic necessities" in terms of self-interpretive and self-creative destining that start from a challenge and ends with its material realisation. Human beings utilise techniques. The interactive relationship between intentionality and artifice, in order to realise projects, and consequently "human nature", is itself technically mediated through the template of how to proceed. The centrality of technique to human technological existence, and consequently "human nature", cannot be overestimated. However, there is not a singular set of techniques for each project. For some projects there are no available techniques (e.g. interstellar travel, world peace, immortality, or time travel) and consequently they remain in the human imagination, fears, dreams, and desires. They are barely challenges. For other projects there are a plurality of techniques (e.g. burning fossil fuel, building nuclear power stations and their networks, building wind power turbines, building tidal power ducts, and using solar power technologies, are techniques for electricity generation).

[24] Cassier (1928), Heidegger (1962), Lukacs (1978), and Ihde (1979).

[25] Cassirer (1928); Ihde (1979).

The question is: how do we choose between them? We should not be radically individualistic and locate the origin of challenges and the destining of their satisfaction in the imagination of the human-subject. This would ignore the social origins of human aims and ends. It would also ignore the technological origins of human aims and ends. Furthermore, if we take technology to be the means by which we move from the challenge to realisation, but resist locating intentionality in the human-subject, then technique is itself only part of artifice. Artifice, by shaping both our horizon of possibilities and the means by which we reach it, provides both intentionality and techniques. Human agency, to the extent it is defined in terms of what human beings can do (as well as by what we can not do), is constructed through artifice and can not be simply taken to be created by human beings. "Human nature" is created by the power/discipline of artifice in the construction of human agency and the destining of the projected horizon of alethic modalities.[26]

Control can not be simply located in the human body. It is only once the embodiment of artifice has become transparent during the construction of the human agent *qua technological human being*, that control can be taken to be the property of the human agent. The centre of control lies in artifice itself. It operates between the human body and the objects to be transformed through discipline/power and embodiment relations of artifice. *Poiesis* is a labour process of feedback relations, mediated by artifice, between the human body and the objects to be transformed. It is primarily a productive process directed towards the manufacture of specific products through feedback adjustments occurring between the practices, technologies, and the materials to be transformed. I shall term this kind of labour process as an economic process. A carpenter making a chair to sit upon, give away, or sell, or a musician performing for pleasure, or for payment, are examples of economic processes. Economic relations with artifice and its horizon of specific goods are primary relationships. Can we make sense of Aristotle's claim that *techne* "resides in the soul of the craftsman" and that the products of *poiesis* find their origin in the producer? As an enframent of practices and materials, using socially embedded technologies, artifice can only be said to be the property of a human agent in virtue of its successful embodiment. We would have to take Aristotle's claims literally in order to make sense of them in terms of the definition of artifice as enframent. *Techne* would reside in the soul of the craftsman *qua technological agent*. If the soul of the eye is "to see" then the soul of the craftsman is "to craft". The soul would be the destining of the craftsman *qua craftsman*. This soul is itself born through the embodiment of artifice as a human body is transformed into a craftsman through such an embodiment. The products of *poiesis* find their origin in "the producer" in the sense that a human body is transformed into "the producer" through the successful embodiment of artifice. Artifice *enframes* through the disciple/power of ordered practice. It conceals itself by its embodiment in practice. Mastery occurs through the successful embodiment of practices as habitual practices conducted with confidence and productivity. The acquisition of technical expertise is not a mastery over artifice itself but, rather, a process of publicly becoming one of artifice's competent servants. The skilled craftsman is an

[26] Of course, artifice is not the only characteristic of "human nature". "Human nature" is also emergent through communicative narrative and social relations (i.e. love, trust, faith, laughter, happiness, authority, etc.). These can be transformed into techniques, but they can also be goods-in-themselves.

exemplar of artifice rather than a master of it. The apprentice imitates the practices of the craftsman and, by doing so, participates in the perpetuation and dissemination of artifice. The craftsman, as an exemplar, is the focus of the apprentice's attention. S/he is taken to be the source of artifice and, consequently, the illusion of mastery is propagated. Furthermore, as the horizon of possibilities is sedimented into human life and artifice is taken to be the property of human masters, the intentionality made possible through artifice is taken to be simple human ends. Artifice is concealed as human means to human ends.

Now *artifice* has been discussed, I can return to the question of whether there are *technai* involved in the building of machines, especially experimental apparatus. If *technai* are involved, which definitions of *techne* are appropriate at which stage of the process of constructing experiments? Given the fact that *techne* is the term for craft-knowledge, and the Ancient Greeks are not famous for their experimental practices, it may well seem odd to the reader to characterise the knowledge at work in highly technological modern experimental physics in terms of ancient craft knowledge.[27] My argument has been that, in order to understand the role of *techne* in modern experimental physics, we need to also understand the role of craft practices, mathematical practices, and *hyle* in experiments. The pre-socratic usage of *techne* captures something of Pickering's term "accommodation" and also Hacking's term "intervention". The word *hyle* captures something of Pickering's term "material agency" because it is emergent through productive practices. It also captures something of Gooding's terms "the participation of Nature", "recalcitrance", "phenomenal chaos", and "plasticity", in his description of the development of craft practices in the early experiments by Faraday. Plato and Aristotle's definitions of *techne* were premised upon knowledge providing the highest degree of communicability, precision, and repeatability, on the basis of "a true course of reasoning". This "true course of reasoning" is given in terms of the unchanging principles of change, and, as the knowledge of the Being of Becoming, is highly characteristic of the alethic structure of the theoretical knowledge of modern physics. This sense of the word *techne* is an important one for the characterisation of scientific knowledge aspired towards during experimentation because "the true course of reasoning", in modern physics, involves the reduction of natural processes by the question "how does it work?" It is constructed in terms of the mathematical representations of "natural mechanisms and causes" as guides to human interventions. Since Moletti and Galileo, the interchangeability of *techne* and *episteme*, based on the belief in the universality and eternality of mathematics, has provided experimental physics with an epistemological warrant for accessing the causal mechanisms of Nature by inscribing machines and mechanical ensembles. It is this sense of *techne*, as an ideal, that is applicable to experimental physics. If we take *techne* to be characteristic of the knowledge aimed for by building repeatable experiments, then *hyle* provides us with a meaningful term to express part of the phenomenological experience of experimentalists of the way that experiments "do their own thing" and resist perfect reproduction. *Techne* is concerned with complete knowledge given in terms of "a true course of reasoning". Such knowledge,

[27] According to Sambursky (1987) and Waterlow (1982) there was a notable lack of experimentation in Ancient Greece for a period of over 800 years. The works of Archimedes and the exploits of the legendary Daedalus were exceptional.

should it occur in experimental physics, would be the *end result* of experimentation. In Gooding's terms, it would lie upon the imagined asymptotic point of convergence. It would provide the abstract, general, and communicable knowledge of how to repeat the experiment.

Novel experiments must occur without *techne* or else there would not be an experiment. If experimentation is to be understood as a form of artifice then we need to define a different kind of productive process. This is the innovative process. In order to define innovative processes we need to analyse how artifice is formed and transformed. It is distinct from invention, which remains an economic process. Invention is the process by which a novel form of artifice is itself produced in order to achieve a specific end. The starting point is that of a challenge and what is lacking is the artifice to achieve it. Invention proceeds from a cultural technical background of artifices, technologies, tactics, and challenges, towards specific end products. Artifices, technologies, and tactics are selected from this cultural background with the aim of constructing an artifice, technology, and *techne*, which will produce the desired product. This constructive process is itself one of the convergence of technological objects from strata of machine-families and integrating them into a unified technological object. These diverse artifices, technologies, and challenges, are brought-together, ordered, and integrated towards the projected asymptotic horizon of *techne*. Diverse artifices, technologies, and technological objects each constitute a centre of transformative discipline/power in their own right. The process of integration requires bringing-together these diverse centres of transformative discipline/power into a coherent single centre of transformative discipline/power. Constructing a new process of destining is itself the object of invention. The construction of destining, the conclusion of the ordering process, is itself the construction of the desired artifice. This process is an *undetermined* process. We cannot know, from the onset, whether or not an artifice, and its technologies, can be produced to produce the desired outcome. Whether a time-travel machine, an anagathic anti-ageing pill, or a cure for cancer can be invented is undetermined. This remains undetermined even when the desired product is produced. The destining, challenges, and transformative powers of even burning coal have yet to be determined. The "trial and error" processes, readily characterised by Pickering's phrase "a dialectic of accommodation and resistance", are an extension of the technological background. The generalisation of this process into an abstract and communicable form of knowledge is the construction of a *techne*. This can be disseminated as instructions of how to repeat the process of production. Experimental physics is inventive when the aim of the experiment is to construct an apparatus to perform a specific task, measurement, or manipulation. Thompson was inventive when he constructed a means to measure the charge to mass ratio of a cathode ray by devising the means to manipulate and inscribe a cathode ray in a cathode ray tube. The construction of the *techne* of how to repeat this experiment brought the Thompson experiment into the public realm. It was also presented, via its *techne*, a something causally understood. Innovation occurs when the productive possibilities of artifice are explored in the absence of a specific end product. This is an alethic process of mapping out the horizon of productive possibilities and the routes that a particular artifice takes to reach them. When a musician explores the productive possibilities of her/his instrument, without aiming to compose a specific musical piece, s/he is engaged in a process of innovation. For innovation to occur there must already exist an artifice and its technologies. However, artifice and its technologies must be *underdetermined*, in the sense that all of their productive possibilities, and their uses, have yet to be determined. The process of innovation is the process of determining the productive possibilities of artifice and the uses of its technologies. For example, music is a complex of artifices, technologies, and challenges. These artifices and technologies are underdetermined because, as of yet, all their productive possibilities have not been performed and written and, consequently, the artifices of composition and performance are not fully explored. Novel experimental physics also takes the form of innovation. The international community of physicists and engineers at CERN are in the process of exploring the productive possibilities of the LEP ring and LHC machines. The Lancaster Ultra-Low Temperature Physics group is exploring the productive possibilities of their dilution refrigerators. These projects are an underdetermined complex of artifices, technologies, and challenges. Their task is one of innovation. Innovative processes are more sophisticated than economic processes. Processes of this kind are both the subject and the object of themselves. An innovative process is fedback onto itself as both its own means and its own end. In these processes the development of the process is itself the product of itself. It is a non-linear process that turns upon itself to explore its own possibilities. It involves the feedback of the uncontrolled control of control back into the process as control-as-information. In experimental physics, as in music, this involves mapping out the contours of human interventions and machine performativity. The physicist learns that when s/he performs a particular intervention then the machine performs in a particular way. Thus the physicist can make a mapping between a range of particular interventions and a range of particular machine performances. However, experimental physicists do not stop at merely mapping out the contours of human interventions and machine performativity. A central part of the art of experimental physics is inscribing these contours with technographe and producing mathematical inscriptions of novel transformative powers. Each machine is an integrated composite of components (which are machines themselves). It is the sum total of an integrated nexus of distinct centres of transformative powers coherently converged into a single centre of transformative power. Associated with each machine are collections of artifices to design, construct, operate, maintain, repair, and interpret the machine performativity. Also associated with each machine are a collection of fragmentary specialised templates to build the machine and its components. These collections, for even moderately complicated machines, will not be embodied in a single human agent. They will be distributed throughout the whole teleological organisation of expertise in which the machine can be brought into existence and integrated as a functioning entity. This will involve the division of the embodiment of these collections among many human agents. Human agents are transformed into functioning technological objects. In experimental physics, as well as engineering and other technosciences, collections of technologies, specialised tools, mathematical techniques, functives, and technographe, will be associated with machinic agency. These interacting clusters of ensembled technological objects constitute machinic agency. Machine agency is constructed as an integration of transformative powers together to produce transformative powers. Thermodynamic devices, electromagnetic devices, electrochemical devices, etc., are all examples of such transformative powers emergent from hybrid machines. These unions are the members of machine-families and the history of their development is a machine-family-tree. Each machine-kind has a cluster of associated transformative powers. These are juxtaposed with the clusters of other machine-kinds when a hybrid is produced; the clusters are transferable throughout a machine-family-tree along the lines of the "genetic" machine-kind. Highly complex machines, such as the DELPHI detector at CERN and an ULT-physics dilution refrigerator, are composites of the members of several machine-family-trees. It is the transferability of clustered technological objects along the "genetic" lines of machine-family-trees that gives these technological objects transcontexturality. This occurs through the overlaps that occur between the machine-kinds used in the construction of complex machines and their templates. For example, the principle of leverage has a "transcontexturality" in so far that it is utilised in the construction of every machine that has a lever as a component. Each historical generation of proto-types constitute strata of machines. The experimental physics of each historical generation is characterised by these strata. The "independence" of the members of any strata, and the "transcendental" nature of the entities involved, is an illusion that occurs through hiding the historical development and the interconnectedness of these machines.

The history of experimental physics is the history of the poiesis, inscription, and extension of machine-family-trees through the invention and innovation of prototypes. The ontology of physics is restricted to these interconnected lineages of prototypes and their associated clusters. Prototypes, such as Thompson's cathode-ray apparatus to measure the charge-to-mass of cathode corpuscles and Millikan's oil drop apparatus to measure the quanta of electric charge were not as independent as Hacking and Bhaskar would like to believe. These experiments shared members of the same machine-kind, electromagnets and capacitors, for instance, and both utilised the same inscription practices. It is the argument of this thesis that "Natural Laws" disclosed through experimental physics are *technai* (in a stratified sense) and the ontology of entities such as electrons, for instance, is limited to the interconnected strata of machines for which electrons are utilised in the inscription and interpretation of their performativity. Electrons are intelligible as technological objects of an equivalent ontological status as G-7 chords. Both of these objects, electrons and G-7 chords, are transcontextural indices that arise through particular modes of enframent (artifice) and are implemented, as principles of organisation and cognition, in the interaction between human agents and machines (or instruments). In this thesis I have raised the question of how technological objects, such as electrons, have been taken to be natural entities. The argument of this thesis is that the transferability between members of natural kinds and machine-kinds is based on the metaphysical precepts of *mechanical realism*. It is this set of precepts that allows the shadows projected upon the cave wall, from the interactive constructive arts of shadow-puppet making and the performative arts of shadow puppetry, to be taken as representational of the truth of reality. It is in this sense that every theoretical and material practice and scientific experience is constructed upon the anvil of practice. The next question is: what is the fire?

The Fire of Hephaestus:

Bhaskar presupposed a mechanical realist ontology from the onset. He argued that if the world were not encapsulated by this ontology then experimental sciences would not exist. I agree that the experimental sciences do presuppose a particular ontology. However, it does not follow from this that (i) that the ontology presupposed by experimental scientists is definitive of the ontology that they actually explore; or, (ii) that the world is exhausted by the ontology of the experimental sciences. Bhaskar asserted, without argument, that "... if science is to be possible the world must consist of enduring and transfactually active mechanisms ...that account in their complex manifold determinations for all the phenomena of our world." (1975, p.20) This is nothing more than a statement of grandiose reductive mechanical realism of the kind that is written in the books of Galileo and Descartes. My argument against Bhaskar is that we cannot find any rational or empirical grounds for deciding between physics-as-discovery and physics-as-productive once we address the technological character of experimentation. What physics does is produce its discoveries as the process of learning how to produce them as an innovative process. Whether or not we presume mechanical realism is a matter of arbitrary choice or cultural practice. Providing that human beings are not the centre and limit of control during the activities of experimentation then experimental physics is intelligible either way. This is sufficient to undermine Bhaskar's assertion that a realist interpretation of experimental science is necessary. At most, it is only necessary that experimental physicists presume mechanical realism. However, the "internal rationale" of any group of practitioners (whether they are experimental physicists, shamanic healers, or whatever) is insufficient as a justification for the validity of that practice to anyone else. It does not follow from the fact that shamanic practitioners claim to contact and use spirits that spirits exist in a realist sense. Nor does it follow from the fact that experimentalists claim to discover and use natural mechanisms that any such mechanisms exist in a realist sense. From an outsider's perspective we can understand the motives of physicists without uncritically accepting their beliefs. Providing we attend to how physicists use their motivations, and beliefs, in the construction of their practices, and their significance, then we can explain how they produce knowledge, and progress, without accepting those beliefs. Furthermore, machines are a part of the world. It does not follow from any success that physicists might achieve in obtaining knowledge about mechanisms at work in mechanical, thermodynamic, electromagnetic, or quantum mechanical machines, that these mechanisms exist outside of those machines. It certainly does not follow that these mechanisms somehow comprise the entire worlding of the world. At most, experimental physics can only justify a modest mechanical realism by revealing the real mechanisms at work in machines. Physics, at most, can only reveal how a part of the world works. That part of the world is restricted to the machines involved. It does not justify the grandiose reductive mechanical realism that Bhaskar presupposed.

I agree with Bhaskar that the mechanisms generated through experimental activity exist independently of that activity only if we construe that activity as an "atomistic event of making a constant conjunction of a set of events" as Bhaskar did (p.13). It is for this reason that Bhaskar considered empiricism to be unintelligible. If experimental activity is atomistic then generated mechanisms must be transcendental to the constant conjunction. However, if we examine experimental activity as an innovative process, situated within an historically generated technological framework that sets-up the trajectory of the process of ordering the technological objects within that framework, then we do not need to examine experimental activity atomistically nor accept a realist interpretation of the emergent mechanisms. They are complex technological objects. We do not need to accept that "the real basis of causal laws are provided by the generative mechanisms of nature" (p.14) if we do not accept that Nature is circumscribed by the machinery of physics. Bhaskar's assumptions lead him into a problem that has haunted the mechanical realists since the seventeenth century. The concept of natural mechanism requires an ontological basis upon a concept of natural necessity. According to Bhaskar (p.14), his concept is that mechanisms "necessarily occur in nature independently of men or human activity". However, his concept of natural necessity was based on two related assumptions: (i) that the "necessity" revealed by experimental physics is natural; (ii) that there is any "necessity" revealed by experimental physics. Both of these assumptions are implicit to his mechanical realism. He did not provide any argument for these assumptions and merely asserted them. He had little choice; his only alternatives were to renounce his realism about physics or remain silent. The first assumption can be countered equally by asserting its arbitrariness. The second assumption can be countered as false. It can be argued that "necessity" revealed by experimental physics is an expression of the closure of discussion and exploration that occurs when the agencies of production and communication have been stabilised against any criticism and controversy. Closure is a product of social and technological processes. Once these processes of production and demonstration have been successfully invented and disseminated, from the standpoint of a scientific community, then the interests of that community can move on. Necessity arises in hindsight through the successful production of acts of reproduction. The maxim that "necessity is the mother of invention" can always be countered with the maxim that "invention is the mother of necessity". The assumption of mechanical realism allows the term "artificial" to be dropped and the adjective "natural" to be inscribed in its place. Nothing more.

Bhaskar argued (p.91) that closure cannot be universal if it has been artificially established. It is a characteristic of techne that it is the general knowledge of causal principles in artificial contexts of production. The establishment of such knowledge is simultaneously an establishment of a closure of what is considered as "a true course of reasoning" involved in bringing something into being. As an act of poiesis, any productive closure is itself, if repeatable, potentially universalisable. In physics, the universalisability of any poietic closure depends upon its successful integration into a nexus of machine-families and its successful utilisation (as a set of functives, techniques, material practices, and interventions) in the extension of a machine-family-tree or the innovation of a new machine-family. Invariance arises as the repeatability of a result through the repetition of intentions, interventions, material practices, and the "true course of reasoning". The invariance is itself a techneic and poietic creation of the transitive process from which it came about. Bhaskar was unable to provide any account of how scientists actually know when they "have produced a theory which correctly describes the mechanisms by means of which the effect in question is produced" (p.110). If we recognise that the theory produced by scientists is techneic in character then we can recognise its establishment in virtue of its repeatability and its successful integration into a machine-family tree (or nexus of machine-families). A techneic theory is one that is used to repeatably produce a specific object utilising the same cluster of technographe, techniques, material practices, and machines. Physical Law, as described by Bhaskar (p.105), has all the characteristics of *techne*. It techneically ascribes the contours of agencies that are utilised in acts of re-production. *Techne* ascribes contours, boundaries, limits, and prescriptions, to a set of agential possibilities that are indexed in terms of causal mechanisms and their effects. As such, it satisfies all the criteria for Natural Law that Bhaskar demanded (pp.105-6) except that it is not necessarily of natural origin. This kind of knowledge can only be described as Natural Law by assuming mechanical realism.

Bhaskar did not provide any account of how we can "distinguish between natural and logical necessity, and between natural and epistemic possibility" (p.38) but his argument depends on establishing a certain and unambiguous method by which we can make such a distinction. There is not any adequate conception of natural necessity, or natural kinds, in Bhaskar's theory of science. He merely presupposed mechanical realism and substituted concepts of alethic modalities for natural tendencies. Bhaskar's argument required mechanical realism as a premise. Once the role that mechanical realism plays in justifying the technological activity of experimental science has been addressed then we can understand experimental sciences, such as physics, without actually being committed to realism about those sciences. When Bhaskar argued for the "Intransitive Dimension" of the transitive (p.17) he was arguing for the Being of Becoming. Knowledge of the "Intransitive Dimension", in the context of production, is the knowledge of the Being of Becoming. This kind of knowledge is *techne*. The human agent, within technological enframent, is "the efficient cause" but is not the controller. The phenomenological experience of "independent behaviour" of the object of experiment, as a resistance to human intervention and inscription, is captured by the Greek term hyle. This is an emergent feature of substance that occurs during the human attempts, guided by *techne*, to inscribe form into materials. It is neither controlled by human intervention, nor does it exist independently of human intervention, and is a property of the context of production guided by *techne*. *Techne*, as the knowledge of the Being of Becoming, arises at the end of any particular scientific work, by generalising the intransient causal principles of change within that work, and offers a repeatable guiding knowledge. The acquisition of *techne* is posited as "the end of experimentation".

Bhaskar made two realist claims about the "intransitive objects" of knowledge (p.22): (i) they are invariant to our knowledge of them; and, (ii) they are science-independent objects of scientific investigation. The assumption of mechanical realism is required before these "intransitive objects" can be categorised as natural objects. It is unsurprising that he concluded that a realist interpretation is necessary. It is essential for any argument for scientific realism that an argument for the ontological categorisation of "intransitive objects" as "natural objects" is provided. Bhaskar merely asserted that they are. This assertion can be countered without any difficulty whatsoever. We need only assert that they are not. However, we can do better than that. Throughout this thesis I have argued that we can examine the objects of scientific discourse as technological objects. These objects can be both intransitive and artificial. How can we make an intelligible account of such objects without assuming realism? This depends upon what we take such objects to be.

Bhaskar argued (p.146) that "...for transcendental idealism the imagined mechanism is imaginary, for realism it may be real, and come to be established as such." An imagined mechanism is taken to be real if it can be pragmatically <u>used</u> as a functive or transdiction in the production, operation, and interpretation of a new machine. I discussed this in chapters three and four. The real/imaginary distinction is based on an immediacy/potentiality distinction of functive utility in the process of extending machine-families. The process of "empirical testing" that Bhaskar described between the imaginary and the real is the process of poiesis that in which a potentially utilisable functive is successfully inscripted and taken to be an immediately utilisable functive. It still requires a presumption of mechanical realism to transdict these functives as representative of "natural mechanisms". The rationale for this step is "justified" by conflating the understanding of truth with the achievement of success in inscribing novel technological powers. The reality of the mechanisms postulated in the model are "subjected to empirical scrutiny" by innovating machinic agency. Bhaskar argued that any philosophy of science must attend to both "the transitive and intransitive aspects of science". It must be capable of sustaining both (i) the social character of science; and, (ii) the independence from science of the objects of scientific thought. However, if we interpret the objects of scientific thought as technological objects, we can produce a philosophical interpretation of experimental physics which satisfies (i) and re-qualifies (ii) providing we take "independence" to have two senses. Scientific realist arguments rhetorically play upon an ambiguity in the meaning of "independence". This ambiguity is that "independence" can be taken to mean either that the objects of scientific thought are (i) not dependent upon scientific thought for their existence, or (ii) not controlled by scientific thought. However, if we examine the objects of scientific thought as technological objects then we can accept sense (ii) without accepting sense (i). We can propose an interpretation of experimental physics that is neither realist nor idealist. Given that science would not exist without scientific thought then the technological objects depend upon scientific thought as a condition of their existence. Unless human agents had thought that technological means could discover natural mechanisms then there would not be any experimental sciences. Without the existence of experimental sciences there would not be any technological objects of scientific thought. However, as technological objects, produced in technological contexts, they are not controlled by scientific thought and are independent from any particular thought about those objects. These objects depend upon the existence of the process of experimental science for their existence. There is nothing more mysterious about this than any creative act of making (e.g. composing a piece of music or inventing a novel dance). As a technological process experimental science is a process which involves the innovation of machinic agency. This process depends on scientific thought, only as a condition of its existence, but it is not controlled by scientific thought.

Bhaskar claimed (p.20) that "the realist principles of substance and causality are shown to be a condition of the intelligibility of experimental activity and the stratification of science... It attempts to express the former in real definitions of natural kinds and the latter in statements of causal laws, i.e. of the tendencies in things." As I have maintained throughout this thesis, even if we accept that experimental physicists seek and achieve causal accounts, in terms of kinds of natural mechanism, it does not follow that these causal accounts actually refer to kinds of natural mechanisms. At most, for the existence of experimental physics as a human activity to be intelligible, it is only necessary that experimental physicists are mechanical realists. It does not follow from the fact that experimental physics exists that mechanical realism is epistemologically justified. The concepts of substance and causality can be made intelligible in experimental physics by examining it as a productive technological activity that operates epistemologically by substituting *techne* for *episteme*, transdictions for natural mechanisms, and machine-families for disclosures, on the basis of assuming mechanical realism. The realist needs to provide an argument for the epistemological warrant of mechanical realism before s/he can claim to have produced an intelligible realist theory of experimental physics. Bhaskar has not provided any such argument.[28] Bhaskar's claim that "[o]nly transcendental realism... can sustain the idea of a law-governed world independent of man" (p.26) should not be surprising because it is merely the definition of transcendental realism. The interpretation of physics proposed in this thesis is not a transcendental realist position and makes no attempt to sustain "the idea of a law-governed world independent of man". In fact, it rejects the notion that such an idea is sustained by experimental physics. There are not any good reasons why any interpretation of physics in particular, or experimental science in general, should attempt to sustain such an idea. The idea proposed in my interpretation is that physics is a rule-guided technological process that is not controlled solely by human agency. The laws produced by experimental physics are techneic and only relate to the parts of the world that are contained within the processes of experimental physics. These parts of the world are non-human participants: they are the machines involved in the physicists' experiments. Even if we accept that physics can successfully produce knowledge about the first and necessary causes at work in such machines it does not follow from this that this knowledge is applicable to any other part of the world. Grandiose reductive mechanical realism is not justified by the results of experimental physics. At most, only modest mechanical realism can be justified by experimental physics. Physics does not need to correspond to any reality outside of itself. It only refers to Nature rhetorically and poetically as a metaphor. When a physicist uses these technological products to ask how natural phenomena come to be, how stars work or how birds fly, s/he is, in fact, asking how s/he would use these products to make a star shine or make a bird fly. S/he makes a model. Even if physicists could make shining stars or flying birds, which presently they can not, they still would need to assume mechanical realism in order to claim that there was only one way to do it, and they knew how Nature did it.

Bhaskar argued that transfactuals, intransitive objects exist, and we need a distinction between sequences of events and causal laws. Even if we accept the existence of transfactuals, or intransitive objects, we are still left with an open question regarding their ontological status. It does not automatically

[28] I do not wish to single Bhaskar out on this point. To my knowledge, no realist (including Galileo, Newton, Descartes, Hobbes, or Hooke) has ever provided an argument for the assumptions involved in mechanical realism.

follow that such objects are natural entities. Of course we need a distinction between sequences of events and causal laws, because these are different kinds of things, but it does not automatically follow that the former are artificial and the latter are natural. It could equally be argued, as I have, that the former are the interactions between human intervention and machine performance; whereas the latter is an abstraction of the mapping of the contours of those interactions in terms of causal principles. Both of these entities are artificial. It is only when mechanical realism is assumed that causal laws are automatically taken as being Natural Law. The distinction between human activity and the causal law is complex. The latter is a product of the former, which can be used as a guide in the process of repeating the activity of production. A technological object is "a man-independent thing" to the extent that within the context of technological enframent, in which it exists, the individual human agent is only one causal agent among many. The other causal agents are the machines, tools, devices, and instruments, also acting within the context of technological enframent, as well as the other people involved. The intransitivity of such agents emerges due to the enduring reproduction of the whole process of experimental physics. However, the existence of physics does not prove the truth of these metaphysical precepts.

It is essential for any realist ontology that it is premised upon the assumption that the world is structured and differentiated. If we are to understand whether or not the world of this ontology can be secured, as differentiated and stratified, by scientific realist argument then we must look at the particular structures and differentiations presented by science. Bhaskar refused to do this on the ground that this is the task of science and not the task of philosophy (p.30). I reject the validity of this division of labour. My own argument is premised upon the commitment that any understanding of the ontology disclosed by experimental physics must be premised upon how that disclosure was achieved. We must also examine how science reveals and presents these structures and differentiations. Again, this is a task that Bhaskar delegated to science. In my view, this refusal to examine experimental science, as it is in practice, is the source of Bhaskar's erroneous presumptions. A philosopher of science cannot neglect how science is actually done, and present a philosophical argument for its validity (or invalidity), as an activity or process, without, at bottom, doing no more philosophical work than merely asserting a set of a priori assumptions and their (possibly) logical conclusions. In other words, the philosopher merely discusses the forms of the shadows of the wall. The weakness of Bhaskar's realist theory of science resides in the fact that he has done nothing more than re-assert the assumptions of the seventeenth century mechanical realists, such as Descartes; whilst simultaneously recognising the historicity of the experimental sciences and their products, as has everyone in science studies since Thomas Kuhn and Michel Foucault. In continental philosophy historicity has been currency since Hegel, Marx, and Nietzsche. Since a discourse of causally efficacious universal invariances at work in the contexts of production and control, is characteristic of techne, it does not follow from the existence of such a discourse that there is any reference to natural invariances, kinds, or causes. Nor does it follow that they are mere fictions either.

Bhaskar asserted that there are levels of reality defined by distinct kinds of mechanism operating under distinct kinds of law-like behaviour. I agree with Bhaskar's assertion for the following reasons. These distinct kinds of mechanisms are transdicted to explain different kinds of machine performativity; their kind is the machine-kind to which they are connected as transdictions. The kinds of law-like behaviour are techneic and are connected to distinct kinds of technique. Each technique is itself connected to a technological object (or set of such objects). It is only through the metaphorical use of machine-families that Bhaskar is able to present them as disclosing distinct levels of reality. Integrating members of different machine-kinds will innovate novel levels of complexity for which new rules and abstractions are required. The claim for the pre-existence of laws to explain complexity is premised upon a deterministic (linear) conception of evolution. However, as an alternative, we can attempt to analyse this process as an underdeterministic (non-linear) transformative process of ordering heterogeneous technological objects. It is experimental and creative. Bhaskar assumed that experimental science encounters "intransitive objects" and produces "transitive knowledge" about them. His "transcendental argument" is a response to the question of what science must be like to provide knowledge of objects of this kind. Bhaskar presumed that science does give us knowledge of intransitive objects, that these objects are natural and pre-scientific objects, and that the "internal rationale" of an activity is sufficient to explain the existence of that activity. However, these are the very assumptions that are at stake in an argument for scientific realism. I accept that Bhaskar has captured the spirit of the enterprise, but we need to ask the transcendental question at a deeper level. What conditions must exist for experimental physics to be possible? No one would deny that there are conditions that make physics possible. However, this fact does not, in itself, support (i) any single claim as to the nature of those conditions; nor, (ii) any claim that those conditions exhaust the content of the world. It is also not an indubitable fact that "the nature of the world can only be known from (a study of) science" as Bhaskar claimed (p.30). This would only be necessarily true if (1) the nature of the world was exclusively created by scientific activity; or, (2) something only constituted knowledge if it resulted from scientific enquiry. Bhaskar explicitly rejected condition (1) and, therefore, we should presume that he endorsed condition (2). However, if he did endorse this condition, this leads to serious problems for his transcendental argument for a realist interpretation of science. He cannot claim to know that realism is the only intelligible interpretation of science unless that is itself a scientific fact. Nor can he establish any intransitivity of any scientific fact without knowing that realism is the only intelligible interpretation. This contradiction results in the irresolvable circularity in Bhaskar's argument: the ontology of science is restricted to that which mechanistic sciences can reveal whilst the epistemology of science is justified by presuming that the ontology of the world is mechanistic. Bhaskar's interpretation is based upon the very "conflation of epistemology and ontology" that he rejected throughout.

Bhaskar stated the following conditions for the intelligibility of experimental activity: (i) the experimenter is a causal agent of a sequence of events; (ii) the causal law identified by the experiment is independent from the experimenters' activities. He defined "law" by using the analogies of chess and cricket. These are the rules that provide us with the "special power of acting in accordance with a plan or in the light of reasons." (p.111) It is a law that allows us to act as causal agents and make a conjunction of events. His analogies are premised upon a metaphorical substitution between a techneic law and an invariant one. The laws of a game are only the rules that we must learn before we play that game according to the rules defined in advance by people who insist that we should play by the same rules. They are as transcendental as the game. They are both instructions of how to proceed and limits to our behaviour. The laws of chess and cricket are positive and negative liberties: they are rights and duties. They are generalisations of how we could repeat the game. They are part of the *techne* of playing chess, or cricket. For a realist, however, the laws of physics should be of a different kind. They are not known, in advance, before we could be said to be doing physics. The aim of physics is supposedly to work out the laws of physics as a result of doing physics. This is the reverse of the games of chess and cricket. Nature is, supposedly, the invisible referee of our actions qua physicists and it is only in virtue of whether we can repeatably perform any particular action, or not, that we can say that we are discovering the laws of physics. But when we take the technological character of physics into account we can actually see how the laws of physics and the laws of a game can be taken to be analogies. Physics is bounded by rules as to what constitutes a legitimate move. Physicists do not investigate the laws of magnetism by dancing naked in woodland groves. They might learn more about Nature if they did, but I have not found any example of a published record of such an experiment. Physicists are limited to specific kinds of material, technical, social, and mathematical practices. These, in many respects, constitute rules of physics. They are instructions of how to proceed, limits to behaviour, and techneic. Furthermore, if the laws of magnetism, for instance, are determined by abstracting the feedback contours between the material and mathematical practices utilised in the experiments, then they too are techneic. The difference between physics and chess, in this respect, is that we learn the rules of chess before playing a game, and these are the same rules for each and every game of chess we henceforth play, but in physics we only learn some of the rules of physics before we can start and discover the rest as we proceed. Furthermore, the rules of physics differ in each kind of experiment we perform according to the different kinds of machine used in that experiment. The argument in this thesis is that the activities of experimental physicists are inscribed within enframing contexts of technological innovation and human agents cannot be considered as the controllers of production. Technology is not completely controlled by human agents despite the fact that its enduring existence is dependent upon the activities of those human agents. Any human agent is only one of the causal agents, at play, in technological activity.

The notion of stratification was essential to Bhaskar's interpretation of science. He argued that explanation and "the real world" are both stratified (pp.169-70). Geometrical optics is explained in terms of Young and Fresnel's wave optics and that, in turn, is explained in terms of the quantum theory of radiation. Bhaskar claimed that a notion of stratification enables us to understand meaning-change providing that the strata of the real world do not change. However, strata of machine-kinds can be re-interpreted by new models, just as they can be re-inscribed with new technographe, and, consequently, we can explain how meaning-change occurs without requiring any notion of "the strata of the real world". The strata of machine-kinds and "the real world" are conflated once mechanical realism has been presumed. The historical development of any science, such as physics or chemistry, can be mapped out in terms of machine-family trees, their innovative interconnection, and the associated clusters of techniques, tools, instruments, technographe, and techniques, that surround machine-kinds and are transported between them at points of interconnection. Such a mapping can represent the totality of the progress of such sciences and the stratification of those sciences. On this account, the stratification of the sciences is identical with the strata of machine-kinds. Ontological depth is the use of subsequently developed strata within a process of "reverse engineering" to transdict the performativity of earlier strata in terms of the later. This is a mode of ontological extension through innovation that is metaphorically used as a mode of explanation of the technological innovation of novel strata. It is my proposal, posited as an alternative to Bhaskar's realism, that the innovation of novel strata can be understood as a creative process. Realism presumes that the world is complete and every possibility is determined in advance. We have no way of knowing this. I have argued that experimental physics does not require such knowledge, or even its possibility, in order to progress. Each innovation of a new stratum is a revolutionary moment. A creative event. These are singular moments in which it is impossible to determine whether the novel prototypes will disintegrate into chaos or integrate into a new order. It emerges from the interconnection of prior strata of technological objects and a synthesis of their associated orders. This requires the invention, the creation, of a new order. This is a process of mutating trial and error that spontaneously generates a novel shift in the ordering process in which heterogeneous objects are combined together into novelties. In any complex process, new levels of complexity can be achieved (almost randomly), which cannot be understood in terms of the previous levels. New rules are in operation and a new organisation is brought into being from the old. This is a new stratum and it is non-reducible to the former. Their rules do not apply. There is no reason to presuppose that this has a unitary source. In fact, it only can occur as the unpredictable and non-linear resultant of heterogeneity. There is no single unitary source of transformative powers. A single source would be homogeneous and, consequently, novel non-reducible strata would be impossible. Unlike cricket, or chess, in a complex process the process creates the rules, because what is brought-forth partially depends on how it is brought-forth and partially depends upon what it is brought forth into. It is the whole process of innovation that is experimental.

Experimental physics, as a technologically innovative process, is directed towards two goals: disclosing mechanisms and making them intelligible. Due to its innovative character, secured within a culture of technological innovation, driven by the psychological desire for novelty, power, and absolute certainty, experimental physics looses interest in its past very quickly. It has no interest in what it has been. It is only concerned in the becoming of itself. Its focus is on the expansion of its boundaries and not upon its histories. The physics community is a heterogeneous convergence of technological objects, groups of humans and machines connected to each other via machines and humans, that is constantly directed towards *its own techne* as the object of its expanding horizon. It seeks out heterogeneity to transform into prototypes of machines, models, and techniques. These strata are standing-reserve as resources for future innovation. Its end is the expansion of itself and an exploration of its own subtleties during that expansion. As an innovative process it is directed towards itself. To understand itself, in its own terms, is to understand the Universe. In order to understand itself, to understand the Universe, it must explore all its possibilities and potentials. It must become everything that it can become. It must consume Nature and replace it with itself. Once it has done this then it will be its own truth. There will be nothing left to do, nowhere to go, and physics will simply cease to exist. All that will be left will be its technologies and no possibility of further innovation. It is a destining driven by the socio-technical organisation of expansive innovation. It is productive of itself through innovation: poetical and technological. It discovers the real by producing the real. It is a form of *poiesis* that enframes itself as its own resource and object. It is an Art. It looses interest in what it has already done and forgets the tentative poeticising in the construction of its own metaphors. In its forgetfulness, it finds its own truths. When it was forgotten that these models were "representative" then they could be presented as the real things. It is this habitualness, and forgetfulness, combined with a innovative headlong rush to discover new powers, that transforms metaphors into techniques, and techniques into truths. On this account, the reality disclosed by experimental physics is not independent of "scientific thinking", but it is also not circumscribed by that thinking. The unfolding character of that reality would not have occurred *as it does* without past efforts to "bring it forth" and, at least in part, those efforts were guided by what was thought to be the best way to proceed. The character of the unfolding reality is, at least in part, dependent upon the character of what is thought about the unfolding reality because that thinking is part of what is "brought forth". Furthermore, the future unfolding of reality depends upon the efforts and projects of the present and those are instigated, at least in part, thoughtfully. Thinking is a part of the reality "brought forth" by experimental physics. However, it is only a part of the "bringing forth". For the "scientific realist", this thesis will express an anti-realist view of science because reality, for the realist, must somehow be independent of what is thought about it. I accept that my position is an anti-realist one, in this respect. The scientific realist insistence on this "independence" is something that not only is arbitrary, historically contingent, and rhetorical, but it is also an "epistemological obstacle" to a deeper understanding of the nature of reality. The notion of "Natural Law" is an archaic mask that has been placed over the mystery that occurs during every act of making. This mystery is a mystery of "bringing forth" itself. "Natural Law" does not help us to understand this mystery. It says nothing more than "it must be so." What is Nature? The mechanical realist will answer that "it is what is necessary". Is it? Perhaps the mechanical realist has pre-empted Nature with her/his mechanistic view. Perhaps "Nature" is not complete and "what is necessary" is perpetually undergoing periods of destabilisation and change. Perhaps it is beyond our comprehension altogether. Any genuine realist must accept that possibility. However, in this thesis, I have been discussing the reality that is intimately bound up with comprehension and mechanistic reasoning. It is that reality which is dependent upon our participation. If we were to stop mathematically innovating new machines then reality would cease being unfolded in that way; unfolding in another way would begin. This ontology is distinct from the idealist identity of reality in the "mind" or "the Absolute". It is a phenomenological ontology in which both reality and truth are "bought-forth" by the process of disclosing reality and truth. Human beings are only a part of that process and do not control its unfolding. Experimental physics is just one possible mode of disclosure amongst all the others. Music is another such mode. It has all the characteristics of physics as a mode of "bringing-forth". It also occurs through human interventions and machine performances, it is also an art directed towards its own perfection, it is a *Ge-stell* which discloses itself as standing-reserve destining towards perpetual novelty; its contours are also inscripted in terms of the artificial *technographe* of musical composition. The only difference between music and physics, on my account, is that music does not attempt to explain how it is possible in reference to "Nature". As a "bringing-forth" it is also a truth. Not a truth in the sense of "correctness", although it can be precise, but a truth in the sense of *aletheia.* It discloses its own truth as disclosure. No one claims that music "corresponds" to an external and objective reality, nor do they claim that it exists only in the mind. The realist-idealist classification does not apply to music. My view is that it does not apply to physics either. The reality disclosed by physics and music is artificial; yet neither are completely controlled by human agency. The question is: what is the source of the artificial? My answer is: why do we think that there is *a single source?* The possibilities of innovation arise from heterogeneity itself.

It is quite arbitrary to isolate a single component of the interconnected complex that constitutes socio-technical agency as the single element responsible for its success. Predictions derived from a theory are only components of the whole socio-technical agency of exoframed experimentation. If we aim to understand any particular experiment in terms of its components then we must examine the complicated and intricate interactions, from their set-up to their completion, in productive processes in which the total connection of the complex involved has primacy over its components. It always remains a question of how these components were used and how they were connected within the whole complex. The task of tracing the function of any single component within a complex is one which is itself another challenge and, as such, it requires another socio-technical agency of analysis to be set-up and performed in order to complete that task. Thus the identification of a single element as responsible for the success of any socio-technical agency is itself a product of further socio-technical analysis. It is not the case that an infinite regression of analysis always leaves a space for the question of how the elements were connected, but, rather, it is more the case that an infinite extension of analysis is required before we could produce a complete account of our understanding of the process. As this always remains an unfinished task then it always remains a question and a challenge. That is destining, if we take up the challenge. The components involved in the whole complex can only be understood in terms of their total concrete interaction within the particular experiment in question as a single complex technological object. All technological objects are complex interactions between other technological objects. There are not any simples. The task of attempting to mentally reconstruct the experiment in terms of isolated components is an endless task. Concepts, functives, material practices, social practices, visualisations, metaphors, machine components, measurements, calibrations, and models are all inextricably bound together in the design, construction, operation, and interpretation of machine performativity. These components can only be understood within the context of a non-linear analysis of production of particular machine performances in terms of the functions that they fulfil within the whole complex. This involves understanding the whole process from beginning to end. Components must be understood in terms of their purpose and performance, as teleological and non-linear, within a labour process and the wider world. In this sense they can not be understood as isolated components at all. Their being is inextricably bound up with the destining of *Ge-stell* and its processes of gathering together and ordering. It is also destined by the organisation of the wider world. No component can exist as a component without the interactions that empower its being. These interactions are themselves the teleological and ontological concrete exercise of transformative powers that can not exist without the whole complex of *Ge-stell*. On this account the notion of "unexercised power" is purely imaginary. Power is only power in virtue of being exercised and, consequently, can only be determined *in hindsight* from within the whole complex of beings exercising powers through interaction. Their potential arises as a consequence of the power that has been exercised upon them, and is only realised as a possibility upon its exercise. The realist project of isolating components in terms of linear "unexercised power" or "unrealised power" is something that is brought to the complex and laid over it as an expression of the imagination. However, the reality of the process does not permit such crudities because each component only achieves its being through the reciprocal interactions with other components, in which no component can achieve its being without others, as a non-linear exercise of transformative power. Each component is an irreversible precondition for the agency of other components and, consequently, the being of the whole process is an irreversible extension of reality through the teleological and ontological challenges of *Ge-stell*. This is the reality of *poiesis* and it is this reality which provides physics with the possibility of discovery. However, the disclosure of *poiesis* is not the disclosure of what existed prior to the experiment but is the disclosure of what the experiment has brought about. It is the disclosure of experimental physics itself. This can only be determined *in hindsight* and the intellectual process of analysing an experiment is *always* one that attempts to understand what was actually done. Thus the understanding of physicists always lags behind the transformative extension of reality that they are challenged to bring about and the physicist can not know what s/he is doing whilst s/he is doing it, because this can *in principle* be only known after it has been done. It can only be known after it has been done because there is no "it" until it has been done. On this account, experimental physics is a creative art that brings beings into the world. The "it" is manifest through the contingent interaction of components and, to the extent that "it" is constructed as a technological object, only achieves "its" transformative power as a consequence of the processes of labour. The processes are socio-technical, cognitive, and material processes, which are contingent upon both the paradigmatic background, against which they are foregrounded, and the teleological positings that emerge from the challenges of *Ge-stell*. They can be determined only from a position of hindsight.

The mathematical projection of the ground-plan of Nature is a form of teleological positing. This consciously executed project promotes detachment and distancing of the subject-object relation in the reflections upon Nature. The mechanical realist conceptual grasp of phenomena as products of natural causes and mechanisms utilises mechanical models as metaphors for the purpose of providing intelligible expressions and visualisations of phenomena as products. In order to understand the construction of such metaphors and their intelligibility we need to address the process of construction as an experimental process (involving social and material practices) that is both challenged as the ongoing process of *Ge-stell* and is underwritten by the mechanical realist precepts. The construction of intelligible communicable accounts of novel phenomena is inextricably bound up with the processes of labour that produce those novel phenomena. During the construction of such accounts there is a continuous interaction between the labour processes involved in the innovation of novel communicative, representational, and material practices. The ongoing mechanical realist process of *Ge-stell* is one that continually challenges physicists to order their practices into a concretely structured complex of inter-related mechanisms available for future innovation. However, due to the metaphysical precepts of experimental physics, the production of intelligible accounts of the causal processes at work in the production of natural phenomena according to natural law is the revealing of truths, in Heidegger's sense of *aletheia*: disclosure for its own sake. Experimental physics is intimately bound up with *poiesis* as a craft and art. It is also bound up with modern technology as *Ge-stell*. It bridges modern technology and craft practices and, as such, reveals Nature as both standing-reserve and truth. The production of technological objects is both a means and an end for further innovation. The end of physics is the innovation of itself. Physics is itself an experiment. If we accept the historical account presented in chapter two then we can see how it began in the fifteenth and sixteenth centuries and it has been innovating itself ever since. By analysing experimental physics in terms of labour processes we are able to address the fact that its successes and failures are the results of protracted historical struggles of heterogeneous organised efforts to stabilise and reproduce socio-technical practices involved in the design, construction, operation, inscription, and interpretation, of machine peformativity, whilst simultaneously situating that process within a world-picture. These efforts are always able to draw upon a background of prior successes and failures. In this respect the successes of experimental physics are not a "miracle" and are quite unsurprising. Or to put it another way, the successes of experimental physics are no more miraculous or surprising than any and every act of making. Making, as one mode of being-in-the-world, is itself only as miraculous or surprising as any other mode of being-in-the-world. Once we have reached this level of truth then we are confronted with the reality that it is Being which is surprising and miraculous. This reality is not explicable by scientific realism and, as a consequence, the successes of experimental physics are not explained by affirming realist metaphysics. The world remains surprising and miraculous however we attempt to explain it, because we need to explain why our explanation should be the case and then explain that further stratum of explanation. This stratified process of explaining could continue indefinitely and still require further explanation. Explanatory realism only functions within the ongoing process of stratification and is perpetually incomplete, and, as a consequence of this incompleteness, does not have any epistemological privilege in the face of the enduring mystery of Being. It can only conceal that mystery. Realism is far from being the only position that does not make a "miracle" out of the successes of physics because it can not fully explain the possibility of experimental physics at all. If it could then what need would we have for experimental physics as a route to truth? We would know the reality that made physics possible. We would know its truth from the onset. Or, was that truth already laid down in advance as the metaphysical precepts at the heart of mechanical realism? My argument has been that it was.

In the above thesis I have argued that the truths and reality disclosed by the processes of experimental physics are "brought forth" as *alethia* rather than mere "facts". Physics aims to disclose mechanisms (reproducible agents) and situate these within its ongoing activities rather than merely compare linguistic truth propositions with experience. The interpretation of experimental physics presented in this thesis situates it upon the boundary between *techne* and *Ge-stell*. Its aletheic modalities are both goods in themselves and standing-reserve for future work. Bhaskar argued for an alethic conception of scientific truth (rather a correspondence notion) in that the transitive dimension of human productive activity produces it. On this point I agree with Bhaskar. However, he did not fully escape the traditional correspondence notion of truth because he limited alethic possibilities by his commitment to the intransitive dimension of natural laws. Labour and its possibilities are circumscribed and delimited to the possibilities permitted by natural laws. Only that which is permitted by natural law can be "brought forth" because natural laws govern the conditions and possibilities of discovering, exercising, and realising mechanisms. Thus, for Bhaskar, human freedom does not consist in an independence from natural law but, rather, in the knowledge of natural laws and the possibility of making them work towards definite ends.[29] Bhaskar equated increased freedom with increased techneic knowledge and the productive powers associated with it. However, my criticism of Bhaskar's conception of alethic truth is that it maintained an implicit connection with the more traditional correspondence notion. It already presupposed a duality between the transitive and intransitive dimensions to the extent that successes *must* be as a consequence of the correct correspondence between human activity and the possibilities permitted by reality. Success occurs as a result of the convergence between these two dimensions. However, I wish to reverse this "order of rank". Bhaskar's conception of alethic truth maintained the traditional reification of the labour processes of experimental work. If we posit that the intransitive dimension is emergent from the trajectories of the transitive labour process *as a totality* then an alternative non-realist interpretation is readily available to us. The teleological positings of labour provide the *poiesis* of agencies with a trajectory destined by the challenges of *Ge-stell*. These challenges are themselves emergent from a background of past efforts and their satisfaction. As Lukacs observed,

"realization is not simply the real result that real men accomplish in struggle with reality itself in labour, but also what is ontologically new in social being in opposition to the simple changing of objects in the processes of nature. Real man, in labour, confronts the entire reality that is involved in his labour, and in this connection we should recall that we never conceive reality as simply one of modal categories, but rather as the ontological embodiment of their real totality." (1978, pp. 122-3)

The objects of any experimental object-sphere are organised according to their appropriateness for the

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[29] This view was also central to Engels conception of the relation between natural laws and human freedom. For example, see Engels (1969, pp.136-7).

poiesis of modes of disclosure. Thus the productive possibilities of these objects are situated within the totality of the labour process according to the teleological positings associated with each and every object and the teleological positing of the whole labour process as a totality. The agential potentials and possibilities of any object should not be attributed to the object, on this account, but, instead, be regarded as properties of the way that they are situated within the organisation of the whole labour process from beginning to end. These potentials and possibilities should not be divorced from the teleological positings of the labour process as a totality, and, without the organisation of agencies within the whole labour process, the objects within that organisation would have no potentials or possibilities whatsoever. Thus labour processes are genuinely creative and transformative. They "bring forth" the unfolding of transformative powers along posited trajectories. The act of "placing" the induced and abstracted *technai* of such processes in correspondence with an intransitive dimension of natural laws, that supposedly pre-exists the processes of labour, is an act of reification of those labour processes. This masks the social ontology of labour with an autonomous "objective world" of mechanised reality. This act of alienation was one that Lukacs termed as "phantom objectivity" (1967, p.83). This "phantom objectivity" places an obstacle to genuine inquiries into the ontology of labour itself. Any genuine inquiry into labour processes should examine the teleology of those processes. Without addressing the goals to which labour is destined, as well as the posited means by which those goals are to be satisfied, then we cannot hope to understand those processes as a mode of organisation of agencies. Since the sixteenth century, experimental physics has posited the form of truth through its mathematical projection of the six simple machines upon natural phenomena. The organisation of the ongoing activities of experimental research has transformed those natural phenomena in accordance with the posited anticipation of the form of truth. Thus the reality disclosed by the labour processes of experimental physics should not be simply categorised as pre-scientific. Rather it should be seen as emergent from genuinely creative labour processes. The agencies "brought forth" by experimentation should be taken to be the products of those labour processes themselves. Thus physics does not necessarily disclose a precedent reality but, rather, produces its own strata of creative transformations of reality as enframed and destined ensembles of machine agencies and strata of transformative powers. However, the techneic causal accounts that are presented as abstracted and communicable understandings of those ensembles and strata are emergent as results of the reproduction of those labour processes. They are constructed in hindsight as a result of extending the closed system and removing all hindrances to its reproduction. The object of this extension is not the natural phenomena of the worlding of the world but is, rather, the creation of new labour processes. In this respect, the object of experimental physics is its own self-creation. Experimental physics is a means of disclosing the potentials and possibilities of itself as both an end-in-itself and a means to future disclosures. It is an art engaged in the *poiesis* of its own trajectories and destining. It is extremely problematical to describe physics as simply a process of the transformation of natural entities, via interventions and representations. It is a complex process of transforming the background of technological organisation and social organisations according to emergent teleological positings made to challenge and transform an ontology comprised of human-machine relations and agencies. It is a "grand experiment"! Whether or not experimental physics could touch the asymptote of objective reality remains perpetually open to question because the art remains incomplete. The teleological positing of the mathematical projection, as a challenge, has yet to reach fulfilment in its own completion and perfection. It is for this reason that the scientific realist has pre-empted the conclusions of the "grand experiment" by declaring that physics has achieved successes. If we examine the reality of the labour processes of experimental physics, from its historical origins to its contemporary trajectories, then, at most, we should limit our pronouncements of success to the more modest acceptance that the "grand experiment" is still ongoing. We have yet to determine whether the "societal gamble" of experimental science was a good move. On this account, the scientific realist interpretation is far from necessary. It is an experimental interpretation of the whole process of labour and *poiesis*. As such it is merely a statement of allegiance and affirmation for the "grand experiment" that we call "experimental physics". At present we are unable to state certainties regarding the mode of being that we call "labour". We do not know the reality of our own being-in-the-world from which labour as a mode of being-in-the-world springs. The "innocence" arises from our state of *thrownness* in the world. The "societal gamble" is that science and technology will improve this state of thrownness. The gamble is that the world will become a better place because it will become more intelligible and human beings will become freer by becoming more powerful. Modern experimental physics is a consequence of the desire for certainty and technological power. It is this desire that is the fire of Hephaestus.

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